

Program on Technology Innovation: Tradeoffs Between Once-Through Cooling and Closed-Cycle Cooling for Nuclear Power Plants

2012 TECHNICAL REPORT

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Product Description

The Electric Power Research Institute (EPRI) has been investigating a number of energy-related water topics that include the implications of retrofitting existing once-through generating stations with closed-cycle cooling, the cost and benefits of closed-cycle cooling, the impacts of impingement and entrainment, alternative fish protection technologies, water use in the electric power generation sector, and advanced power plant cooling technologies.

Background

The electric sector is facing a number of regulatory mandates under the Clean Air Act, the Clean Water Act, and the Resource and Conservation Recovery Act (RCRA). One of the most challenging is § 316(b) of the Clean Water Act governing fish protection at cooling water intake structures. These regulatory actions will result in significant costs to the electric sector and thus increases in the cost of electricity as a result of compliance. Many fossil units are likely to retire rather than retrofit expensive equipment to older units, especially given current natural gas prices.

Objectives

The objective of this report is to summarize the tradeoffs between once-through and closed-cycle cooling for existing and new nuclear generation units.

Approach

The study drew from research conducted by EPRI, engineering and scientific organizations, federal agencies, national laboratories, and international organizations. The report summarizes information from disciplines that include engineering, economics, biology, and environmental disciplines necessary to cover the complex considerations regarding the tradeoffs between once-through and closed-cycle cooling systems relative to nuclear generation.

Results

Both new and existing power plants are likely to be impacted in terms of additional operational requirements as a result of new Clean Water Act § 316(b) regulations for fish protection. For example, EPRI estimates the cost to retrofit existing nuclear facilities with closed-cycle cooling (in response to potential § 316(b) regulations) to

be in excess of 32 billion dollars. Although cooling towers would reduce impingement and entrainment mortality, closed-cycle cooling results in a variety of potential site-specific environmental and social impacts that include noise, salt drift, visible plumes, roadway icing and fogging, safety issues, and impacts to terrestrial vegetation and wildlife. Additionally, consumptive fresh water use from closed-cycle cooling is estimated to be at least double that of once-through cooling. This is at a time when fresh water is an increasingly limited resource in many regions of the United States.

Nuclear generating units are especially limited in their ability to retrofit new cooling towers due to space constraints, safety issues, and cost. In particular, use of dry cooling is not feasible. This is due to the fact that the lower steam temperatures associated with nuclear plants result in higher efficiency penalties from the higher back pressure associated with dry cooling. In addition, the ability to meet safety and risk requirements for nuclear units would likely require indirect dry cooling, which adds to the expense and efficiency penalty of the technology. But some nuclear sites have the potential to accommodate equally effective alternative technologies and operational measures to protect fish and aquatic life. Requirements to retrofit cooling towers would, in the majority of cases, reduce plant generation as a result of heat rate and energy penalties and might preclude new nuclear units at some existing sites as a result of the additional space requirements necessary to accommodate closed-cycle cooling.

Applications, Value, and Use

This report is intended to provide decision makers and other stakeholders with technical information regarding the environmental, financial, and operational tradeoffs among various technological options for meeting anticipated regulatory requirements for fish and aquatic organism protection at nuclear power plants. The report also addresses issues such as water consumption associated with cooling systems and opportunities to reduce water consumption.

Keywords

§ 316(b)
Closed-cycle cooling
Cooling towers
Fish protection
Once-through cooling

Abstract

This report reviews the potential tradeoffs for nuclear generating facilities between once-through and closed-cycle cooling resulting from three regulatory and policy drivers: Clean Water Act Section 316 (a) regulations on thermal discharges from once-through cooling systems; Clean Water Act § 316(b) regulations on entrainment and impingement at cooling water intake structures (CWISs); and increasing water use pressures on fresh water resources in many regions of the U.S. The report summarizes the status of thermal discharge requirements and § 316(b) regulations, cooling water use in power plants, water availability in the United States, and the different kinds of closed-cycle cooling systems that are applicable to nuclear units. This report also reviews the current population of nuclear facilities, nationally and internationally and identifies unique characteristics of nuclear facilities relevant to cooling water use. The consumptive water use implications for both existing and new nuclear facilities are examined, as well as the availability of alternative technologies to protect fish and shellfish from impingement and entrainment mortality at CWISs. Finally, the report discusses the implications of retrofitting U.S. nuclear facilities with closed-cycle cooling from the standpoint of cost, environmental considerations, and benefits, drawing heavily from the results of the Electric Power Research Institute's (EPRI's) research programs.

Executive Summary

Water is essential for human existence, food production, sustainable development, and economic productivity. Water is also essential to energy production—98% of electricity generation in the United States depends on water for cooling or as the motive force to drive hydroelectric plants. On the basis of water withdrawal rates, electricity generation from power plants is a major water user, rivaling agriculture as the nation's largest demand on fresh water. However, unlike agriculture, most of the water withdrawn from source bodies of water is returned (not consumed), typically at 10–20 degrees warmer than when originally withdrawn. On the basis of water consumption rates, electricity generation uses about 3.3% of the U.S. fresh water resources. Supplies of fresh water are constant and largely unexpandable. Demand for fresh water by sectors of the U.S. economy has been increasing for decades. Competition for limited water resources in many parts of the United States is predicted to increase.

Most large electric power plants—including both fossil-fired and nuclear plants—employ one of two types of cooling system designs: (1) once-through cooling, which withdraws water to extract waste heat from the plant and returns it to (usually) the same body of water, where the heat is dissipated; and (2) closed-cycle cooling, in which heat is rejected to the atmosphere by evaporation of cooling water. Use of closed-cycle cooling dramatically reduces the amount of water that is withdrawn from the source body of water (that is, by up to 90% compared to once-through cooling). The water consumed in this process is a result of evaporation and "blow-down" of accumulated solids and salts. Most references estimate that closedcycle cooling consumes more than twice as much water as is consumed by evaporation from a "thermal plume" in the source body of water from once-through cooling system operations. Approximately 40% of U.S. nuclear plants use closed-cycle cooling with the others using once-through cooling.

If plant efficiency and economics were the only consideration, then once-through cooling would dominate and would continue to be a preferred option for new and existing generating units. However, since the 1980s, most new plants have been designed with closed-cycle cooling. Three regulatory and/or policy drivers have affected this development:

- 1. Concern for potential impacts of the heated water discharged back to the source body of water
- 2. Impacts of the plants' cooling water intake structures on fish and aquatic organisms
- 3. Fresh water availability, especially in arid regions of the United States or regions without large bodies of water from which to withdraw cooling water

The Clean Water Act regulates the first two of these drivers and has been a major factor in the shift toward closed-cycle cooling over the last two or three decades. In contrast, no federal regulations serve as a "driver" to manage the consumptive use of water. As a result, state, regional, and commercial interests are the largest drivers in this area. As discussed in this report, managing the energy-water nexus is becoming increasingly important, and efforts to coordinate among federal and state authorities on water management are often fragmented.

The purpose of this report is to examine all three of these drivers in an integrated and holistic manner, with significant emphasis on the second and third drivers. This report addresses:

- Once-through cooling and closed-cycle cooling technology options. Choices of preferred technologies are highly site specific, which has led to a wide range of technical alternatives, including cooling towers (mechanical and hyperbolic), cooling ponds, cooling impoundments, dry cooling technologies, and hybrid cooling systems that use both wet and dry cooling, as well as a wide range of environmental technologies to minimize impacts on aquatic life.
- U.S. and international nuclear plant data on cooling system design choices.
- Tradeoffs that should be considered in evaluating cooling system design choices, focused on the advantages and disadvantages of once-through and closed-cycle cooling.
- Extensive research by the Electric Power Research Institute (EPRI) to evaluate the costs, benefits, and environmental impacts of these choices, with a focus on the impacts of a potential mandate to retrofit closed-cycle cooling on currently operating fossil and nuclear facilities.
- Water consumption data relative to closed-cycle versus oncethrough design choices for both current and future plants. This report attempts to quantify, based on best data available, the

impacts of widespread expansion of closed-cycle cooling on the consumptive use of water.

Estimated environmental impacts of once-through cooling on source bodies of water. Clean Water Act regulations are focused on preventing adverse environmental impacts on aquatic life as observed at the cooling water intake structure and discharge. EPRI research, including extensive literature searches of peerreviewed and other independent studies, has focused on estimating localized impacts (impingement and entrainment at the intake structure and thermal discharge) and any measurable and sustained adverse impact on aquatic life in the source body of water.

Key findings and conclusions from this study include:

- Currently operating U.S. nuclear plants rely heavily on oncethrough cooling. A requirement to retrofit the 60% of nuclear units that currently use once-through cooling with closed-cycle cooling would be extremely expensive and result in extended outages. (EPRI estimates an average of six months' outage time for the 39 once-through cooled sites and up to a year and a half for some sites.) Retrofitting would result in a variety of potential environmental and social impacts with relatively small comparative benefits to the affected bodies of water. There are many cost and biologically effective alternative technologies to closed-cycle cooling for sites where aquatic life protection is an issue. EPRI estimated that retrofitting all existing once-throughcooled nuclear plants would cost the nation over \$32 billion (net present value). The cost would extend to approximately \$100 billion when fossil plant retrofits are included. The annualized cost of mandating these retrofits was estimated to be almost 800 times greater than the monetized commercial and recreational fishery benefit.
- Due to a variety of factors discussed in this report, dry cooling is not considered practical for nuclear power plants. Indirect dry cooling has been proposed for only one new nuclear power plant, as part of a hybrid cooling system. EPRI is considering a research program that would investigate the design, safety, and regulatory hurdles that would have to be overcome to use dry cooling more broadly in nuclear power generation.
- The United States relies much more on fresh water for nuclear plant cooling and less on saline bodies of water (that is, oceans, estuaries, and tidal rivers [O/E/TRs]) than other nations, by more than a factor of two. The United States relies much more on closed-cycle cooling and much less on once-through cooling for its nuclear plants than other nations, by a factor of about 1.7.

- The United States is anticipated to rely extensively on existing nuclear plant sites as the location for additional nuclear reactor capacity. Roughly 60%–80% of future nuclear capacity is anticipated to be constructed on existing nuclear plant sites, based on current trends. The proposed § 316(b) regulation would likely limit this option for siting new units at many existing nuclear sites as a result of space constraints and/or permitting issues for cooling towers.
- Based on an EPRI study of fresh water withdrawals, existing water resources, and future demands, it is clear that water supply considerations will be an increasingly important factor for future power generation. Increased focus on efficiency of water use and conservation is needed to meet future water needs and the growing demand for energy simultaneously.
- Based on the best data available, closed-cycle cooling technologies are estimated to consume at least twice as much water as once-through cooling technologies. This finding is based on research by the National Renewable Energy Laboratory (NREL) using the most recent data. NREL notes that these data contain gaps and methodological inconsistencies. More research is needed on this issue.
- The proposed § 316(b) rule for existing facilities developed by the Environmental Protection Agency (EPA) evaluated a wide range of societal impacts that would result from mandating closed-cycle cooling in existing U.S. electric plants, including impacts on grid reliability, plant closures, and capacity losses. However, the EPA did not evaluate the impacts on consumptive water use and the resulting impacts on the competing water demands from different stakeholders.
- Recent research by the National Energy Technology Laboratory (NETL) evaluated the increased consumptive use of water under five different scenarios related to the conversions of power plants to closed-cycle cooling. Based on this research, the regional variations are expected to be significant.
- EPRI research has examined the estimated impacts of oncethrough cooling on source bodies of water. The results of a July 2011 report, *Do Power Plant Impingement and Entrainment Cause* Adverse Changes in Fish Populations? A Review of the Scientific Evidence (EPRI report 1023094), are summarized in this report. The EPRI study relied on peer-reviewed reports, blue ribbon commission reports, and other highly credible independent studies that focused on potential impacts on the source body of water, that is, overall or large-scale impacts beyond the immediate vicinity of the plant. EPRI found that

virtually all of these independent studies identified little or no evidence of environmental impacts on the aquatic populations in the source bodies of water associated with power plant cooling operations.

- Nevertheless, EPRI has examined a wide range of commercially available fish protection technologies for minimizing the potential for adverse environmental impacts. Although their performance is highly site- and species-specific, many of these technologies have demonstrated highly effective performance results, especially in minimizing impingement mortality. Many of these technologies were not developed and demonstrated two or three decades ago when closed-cycle cooling was commonly used for Clean Water Act compliance at new facilities.
- There are opportunities for balancing the associated tradeoffs between the use of once-through cooling and closed-cycle cooling for new plants, especially where fresh water resources are limited. These situations could include:
 - New plants where consumptive use of water is a priority consideration (for example, the upper Great Lakes).
 - New plants in O/E/TR regions. This is a more difficult situation for the possible use of once-through cooling because these O/E/TR regions may have more stressed fisheries and because consumptive use of fresh water is not an issue in these regions. However, new plant siting in these regions may have an indirect impact on the consumptive use of water if it eliminates the construction of other generation sources using fresh water.
 - New plants that utilize cooling ponds or small reservoirs for heat dissipation (cooling ponds consume less water than cooling towers).

As cooling water resources become more constrained and as available land for power plant siting becomes more limited in the decades ahead, siting of new generation capacity will become increasingly challenging. This will place increased emphasis on the optimum utilization of existing generation sites, with their established transmission access, water access, and infrastructure for fuel storage and handling among other factors.

There are many examples where alternative technologies have been used to provide for once-through cooling in lieu of cooling towers where consumptive use of water is a concern. Alternative or "non-traditional" water resources will also play larger roles in the future.

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Section 1: Introduction

The generation of electric power generally requires use of water, a resource that is used for a myriad of purposes. EPRI research has been focusing on a number of topics that are directly and/or indirectly related to water quality, fish protection and sustainable water use that include:

- Water use and conservation in the electric power generation sector
- Implications of alternative forms of generation to provide power in a carbon constrained world (i.e., EPRI's Prism program)
- Advanced cooling technologies
- Impacts of impingement and entrainment and the cost and benefits of reducing them with closed-cycle cooling
- Fish protection technologies, and
- Costs, benefits and other impacts of retrofit of cooling towers to existing once-through cooled generating stations.

New regulatory initiatives, including §316(b) under the Clean Water Act (CWA), Mercury and Air Toxics Standards (MATS) under the Clean Air Act (CAA), and Resource and Conservation Recovery Act (RCRA) Subtitle D, all have the potential to significantly affect existing generation in the U.S. Greenhouse gas emissions limits for new and existing units are also being established under the Clean Air Act. Many older fossil facilities may be retired, rather than retrofit expensive equipment to older units, especially given current natural gas prices, resulting in the need for new generation.

New nuclear projects will have to address water availability for cooling as part of the tradeoffs between efficiency, cost, and other impacts. This consideration is also potentially applicable to existing nuclear generation, as two of the current §316(b) options under consideration are based on closed-cycle cooling as the Best Technology Available (BTA).

The electric power generation industry is one of the largest water users in the U.S., with total withdrawal approximating that by agriculture. However, in contrast to agricultural use, most water use by electric power is "nonconsumptive" – that is, most water used for once-through cooling is returned to the source waterbody. Prior to the 1970's the majority of thermoelectric (or steam electric) generating facilities used once-through cooling systems, in which cooling water is withdrawn from a source waterbody, passed through a condenser where turbine exhaust steam is condensed and then returned to the source

waterbody. In recent decades, most new facilities have employed closed-cycle cooling, in which the cooling water, after passing through the condenser, is pumped to a cooling tower where it is cooled by evaporating part of the water to the atmosphere which cools the remaining water. This cooled water is then recirculated back to the condenser. This is essentially a closed loop system except for water loss through evaporation and blowdown and the compensating makeup. Closed-cycle systems significantly reduce the volume of surface water withdrawn compared to once-through cooling, typically by more than 90%, but significantly increase water consumption, relative to once-through cooling.

Historically, there have been three primary drivers for the shift from oncethrough cooling to closed-cycle cooling that include:

- 1. Concern for the potential impacts of the heated water discharged back to the source waterbody;
- 2. Impacts of the cooling water intake structure as a result of impingement of larger fish and aquatic organisms on water screens used to prevent debris and fish from plugging the condensers and the entrainment of smaller fish and aquatic organisms that are exposed to heat, mechanical stress and biocides as they pass through the cooling water system; and
- 3. Freshwater availability, especially in arid regions of the U.S. or regions without large waterbodies from which to withdraw cooling water.

As discussed in this report, roughly half of today's fleet of electric power plants still use once- through cooling. More specifically, about 60% of nuclear plants use once-through cooling and 40% use closed-cycle cooling. This ratio is essentially reversed for fossil plants.

In recent years there have been regulatory initiatives resulting in increased use of closed-cycle cooling for all generating facilities. These initiatives could result in potentially significant impacts to both fossil and nuclear generating facilities. A regulatory requirement to retrofit cooling towers would be an economic and engineering challenge for nuclear generating facilities. This report documents the trade-offs between once-through cooling and closed-cycle cooling applications for thermoelectric generating plants, including important supporting data.

Sites are often selected to supply baseload electricity to population and industrial centers in the region of those sites, even if they have less than optimum cooling water resources. As discussed later in Chapter 2, the once-through cooling option, if available, has significant advantages for plant efficiency, economics, and other factors. However, if a plant is sited in a region with limited cooling water resources (e.g., only small rivers are available in the region), then closed-cycle cooling may be required to avoid complete diversion of the river or excessive heating of the source waterbody. Cooling towers withdraw substantially less water and reject most of the plant's excess heat into the atmosphere, reducing the thermal impact on the source waterbody. Thus, closed-cycle cooling is almost always used for plants on small rivers or those using groundwater. This preference for closed-cycle cooling in such siting applications is equally applicable to all large baseload thermoelectric plants – both nuclear and fossil-fired facilities.

Subsequently, in the 1970s and 1980s, EPA regulations governing cooling water intake structures (CWISs) resulted in a second reason for increased use of closed-cycle cooling for new facilities: to address potential CWIS impacts to fish and aquatic life.

Shifting cooling systems from once-through cooling to closed-cycle cooling has positive and negative impacts. Closed-cycle cooling enables a large reduction in the volume of cooling water being withdrawn, but increases the volume of cooling water consumed, typically by a factor of two or more. According to the USGS, *withdrawal* is defined as the amount of water removed from the ground or diverted from a water source for use, while *consumption* refers to the amount of water that is evaporated, transpired, incorporated into products or crops, or otherwise removed from the immediate water environment.

For once-through cooling, the water is pumped through the plant, where it is used to condense the steam from the turbine, and then is returned to the original waterbody some 10° to 20°F warmer. This process requires large volumes of water, but consumes very little of that water, other than the incremental evaporative loss due to the increased water temperature. Once-through cooling evaporative loss tends to be site-specific depending on where it is discharged (i.e., at the surface or on the bottom of the source waterbody), whether the thermal plume sinks or floats, and how quickly it mixes, which is highly dependent on the waterbody type (i.e., tidal, riverine or lake/reservoir). It can also be affected by meteorological conditions such as wind speed and air temperature. On the other hand, closed-cycle cooling generally withdraws 90% to 98% less water, but consumes most of the water withdrawn through evaporation and drift – causing the near complete loss of that water (90% loss).

The electric power generation industry accounts for approximately 40% of U.S. water withdrawals, roughly the same as agriculture (see Figure 1-2). However, actual power plant consumption is estimated to be only 3.3% of total U.S. freshwater consumption -- much less than municipal water needs, and significantly less than agriculture (see Figure 1-1).

The Clean Water Act (CWA), which regulates thermal impacts and CWIS impacts, has been a large driver in the shift in thermoelectric plant cooling from once-through cooling to closed-cycle cooling (see Section 2.4 for details on the CWA). However, there are no equivalent Federal regulations or policies governing the environmental issues associated with consumptive use of water. As discussed in Chapter 5, fresh water shortages and water use conflicts are on the rise in many parts of the U.S. and globally.

U.S. Freshwater Consumption, 100 Bgal/day

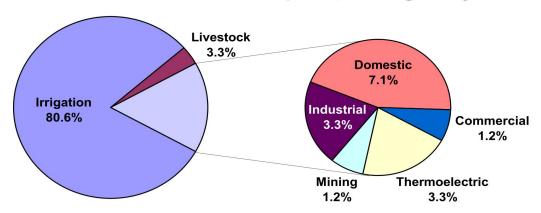


Figure 1-1 Estimated Fresh Water Consumption by Sector, 1995 (DOE Report to Congress, 2006)

U.S. Freshwater Withdrawals, 345 Bgal/day

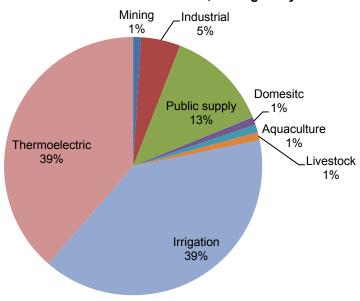


Figure II-I. Estimated Freshwater Withdrawals by Sector, 2000 (Hudson et al., 2004)

Figure 1-2 Estimated Fresh Water Withdrawals by Sector, 2000 (DOE Report to Congress, 2006)

For context, EPRI nuclear members with expertise in cooling water issues were assembled for an EPRI-DOE-INL-sponsored working group meeting in April 2010. These attendees ranked "consumptive use of water" as the most important issue that EPRI and DOE R&D programs should address. Further, the group stated that "Water is the pivotal issue for new nuclear plant siting."

Chapter 2 provides background information on how water is used to generate electricity, basic definitions for technical terms used in the report, an overview of the Clean Water Act relative to cooling water use and an overview of alternative fish protection technologies. Chapter 3 provides a description of the nuclear facilities in the U.S. and worldwide. This includes information on the overall water withdrawal and consumptive use data associated with the once-through cooled nuclear units, differences between once-through cooling uses for nuclear versus fossil units, and new plant considerations.

Chapter 4 provides an overview of the differences between once-through cooling and closed-cycle cooling in terms of impacts to fish and shellfish, environmental impacts, cost, efficiency and economic performance. Chapter 5 provides an overview of the differences in consumptive water use between once-through cooling and closed-cycle cooling, and provides estimates, based on best data available, of the potential impacts of widespread expansion of closed-cycle cooling on the consumptive use of water in the U.S. Chapter 6 provides a review of the potential impacts of requiring U.S. once-through cooled nuclear facilities to retrofit to closed-cycle cooling, with information provided on alternative closed-cycle cooling technologies, cost and environmental impacts. Chapter 7 provides information on the range of fish protection alternatives, including a summary of the currently employed technologies and mitigation measures used at many existing once-through cooling nuclear facilities. Chapter 8 provides the report's summary and conclusions.

Section 2: Background

This Chapter provides background to better understand the tradeoffs between once-through and closed-cycle cooling. It provides an explanation of how nuclear power plants use cooling water, some basic definitions for key terms and concepts used in the report, a summary of different types of closed-cycle cooling systems and a summary of the Clean Water Act statutory and regulatory programs governing the use of once-through cooling.

2.1 How Power Plants Use Cooling Water

All thermal power plants (fossil and nuclear) using steam turbines to drive the generator must condense the low pressure steam exiting the turbine to water, in order for it to be pumped back to the boiler, reactor or steam generator at the pressure of the steam turbine inlet. The heat released in the condensation process must be rejected to the environment as required by the laws of thermodynamics governing the behavior of thermal cycles. In practical terms, in the case of these Rankine steam cycles, condensation is required because if the steam were compressed back to turbine inlet pressure in the vapor phase, the energy to compress it would exceed the energy extracted from the steam during its expansion through the turbine.

The quantity of heat which must be rejected to the environment can be quite large, amounting to 60% to 70% of the heat generated by the plant for coal and nuclear plants. For fossil plants, a good portion of this heat is lost up the stack, while for nuclear plants, virtually all the waste heat must be rejected through cooling water systems. For natural gas combined cycle (NGCC) plants, thermal efficiency can exceed 55%, so the quantity of heat that must be rejected to the environment is much lower. In order to maintain the required turbine exhaust pressure at typical operating levels of 1.5 to 3.5 inches Hga, the steam condensing temperature must be held at 90°F (for 1.5 inches Hga) to 120°F (for 3.5 inches Hga) necessitating the availability of a cooling water at temperatures no greater than about 70°F to 100°F. As water temperatures exceed the design maximum, the plant would have to reduce steam flow to the turbine to stay below the turbine back pressure limit (and prevent a unit trip). This has the effect of reducing capacity and decreasing efficiency.

The amount of cooling water required depends on the type of cooling system used and the size and design of the condensers. For once-through cooling, where water is withdrawn from a natural source (e.g., river, lake, ocean or reservoir) and passed through the steam condenser where it absorbs heat and then is returned to

the source, typical cooling water flow rates are 500 to 700 gallons per minute per MW. For a 1,000 MW plant, this corresponds to 700 million to 1 billion gallons of cooling water flow per day. If a closed-cycle wet cooling system is used, the water cycles between the cooling tower, where heat is removed by the evaporation of water, and the steam condenser, where heat is absorbed to condense the steam. Typical evaporation rates for cooling towers range from 8 to 12 gallons per minute per MW (exclusive of blowdown), or 12 to 18 million gallons per day for a 1,000 MW plant.

2.2 Basic Definitions

Once-through Cooling - Once-through cooling is the process whereby a steam generating facility withdraws cooling water from a source waterbody (ocean, river, lake or estuary), passes it through the cooling system, and returns it to the source waterbody. The cooling water is typically drawn through a bar rack and/or screen to remove debris and/or aquatic organisms, and pumped by the circulating water pump through the tubes of a steam condenser. The steam from the turbine exhaust is condensed on the outside surface of the condenser tubes, and the condensate is returned to the boiler, steam generator or reactor to generate steam for the turbine. The condenser cooling water is discharged back to the source waterbody at a typical 10°-20°F differential temperature. A typical once-through cooling system is shown schematically in Figure 2-1.

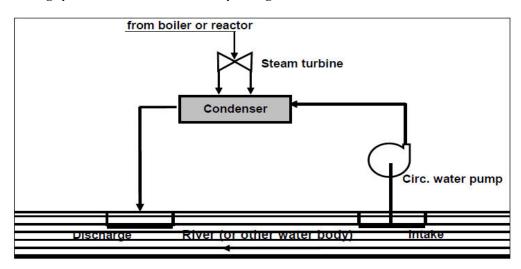


Figure 2-1
Once-through cooling system schematic

Closed-cycle Cooling - Closed-cycle (or recirculating) wet cooling systems are similar to once-through cooling in that the steam is condensed in a water-cooled, shell-and-tube steam condenser, but differ in that the heated cooling water is not returned to the environment but is conveyed to a cooling component, typically a wet cooling tower where it is evaporatively cooled and then recirculated to the condenser. A typical closed-cycle wet cooling system is shown schematically in Figure 2-2.

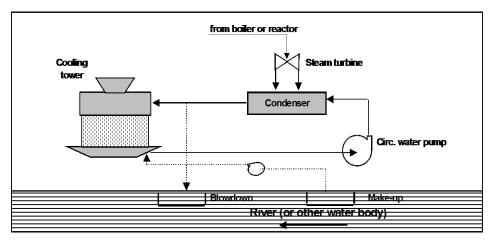


Figure 2-2 Closed-cycle wet cooling system schematic

Blowdown – As water is evaporated in the cooling tower, salts and solids (Total Dissolved Solids – TDS, and Total Suspended Solids, TSS) in the cooling water increase in concentration. To prevent scaling, fouling and corrosion in the closed-cycle cooling system and to meet water quality standards at the point of final cooling water discharge, water must be periodically discharged from the closed-cycle cooling system (i.e., blowdown) and new cooling water make-up withdrawn from the source waterbody to replace evaporative water loss, drift and blowdown.

Drift – During cooling tower operation, a percentage of the circulating water flow will be expelled along with the heated air plume, in the form of small water droplets, or drift. Cooling towers typically have mist eliminators to capture most of the droplets before discharge, and the drift rate (loss of water droplets in the cooling tower plume) is typically less than 0.0005% of the circulating water rate.

Cooling Water Intake Structure – The cooling water intake structure begins at the point of initial construction for cooling water conveyance to the condensers and ends at the point of discharge from the cooling water pumps. The point of initial construction may be the entrance to an offshore pipe, an intake canal, constructed embayment or the bar racks used to prevent large debris from damaging the passive or traveling water screens.

Impingement – The process whereby fish or shellfish are caught on cooling water intake structure screens used to prevent debris or fish from blocking or plugging cooling water condenser tubes. Most U.S. power plants have 3/8-inch square mesh screens but some have rectangular shaped or larger or smaller screen mesh sizes.

Entrainment – The passage of smaller fish, shellfish or other aquatic organisms through the screens, cooling water pump, condensers and associated piping and then discharged back to the receiving water. In this process aquatic organisms are exposed to mechanical stresses and pressure changes of the pumps and piping, to

biocides if they pass through the system during intermittent chlorination (or other biocides used), and to temperature differentials in the condenser tubes.

A more comprehensive list of definitions can be found at §125.92 of the 316(b) Proposed Rule.¹

2.3 Types of Closed-cycle Cooling Systems

Currently, there are a variety of closed-cycle cooling systems available for use. These systems vary in terms of their cost, efficiency, space and water use requirements, as well as their compatibility for use with nuclear facilities. A brief review of these alternatives follows.

2.3.1 Wet Cooling Towers - Mechanical Draft

Wet cooling is achieved by evaporating a small fraction (typically 1 to 2%) of the water circulated through the tower in order to cool the remaining 98 to 99% of the water. Mechanical draft towers use fans to bring atmospheric air into contact with the water to achieve the evaporation. Figure 2-3 shows a schematic of a single cell of a typical counter-flow mechanical-draft, wet cooling tower. Figure 2-4 shows a photograph of an installed tower consisting of 32 cells. The tower can be configured in a variety of ways. Most are rectangular, made up of a number of individual cells (square or rectangular in shape), each cell with its own fan. The cells can be arranged in either an in-line or a back-to-back configuration. Finally, some round designs exist and can be either induced-draft (where the fans are at the top of the tower and draw air up through the cells) or forced draft (where the fans are on the side of the tower and push air through the cells).

¹ Federal Register, Vol. 76, No. 76, April 20, 2011, pg. 22281.

² These values apply to situations where the cooling water source is fresh water and the cycles of concentration can therefore be higher. In high salinity situations, where more frequent blowdown is needed to reduce accumulations of solids, the cycles of concentration are lower, and more makeup water is required. Note that fewer cycles of concentration in turn require more blowdown (and hence more withdrawal), but not more evaporation (and hence not more consumption).

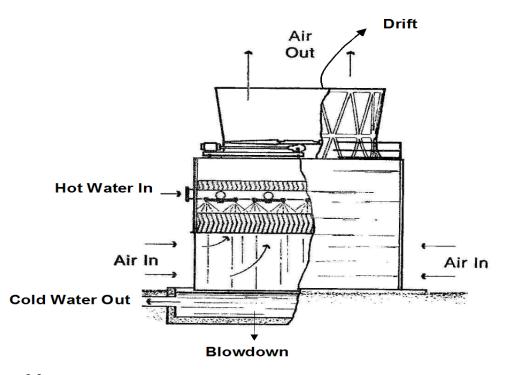


Figure 2-3 Schematic of mechanical-draft wet cooling tower



Figure 2-4 32 cell, mechanical-draft, counterflow wet cooling tower

The system operates by pumping water from the condenser to the top of the tower onto a hot water distribution deck on spray headers. The water then flows down through nozzles in the deck or header, which breaks it up into droplets and distributes the droplets uniformly onto the fill. The water flows through the fill in thin films or droplets depending on the type of fill, creating a large interfacial surface for contact with the air. Fresh air is drawn (upward for counter-flow fills, across for cross-flow fills) through the fill and into intimate contact with the falling water. The cooling is accomplished by the evaporation of a small fraction (approximately 1 to 2%) of the water. The cooled water then falls into a cold water collection basin beneath the fill from which it is recirculated back to the condenser inlet.

Some portion of the circulating water flow is discharged as "blowdown" from the system back to the environment in order to control the build-up of total suspended and total dissolved solids (TSS and TDS) brought into the cooling system with the make-up water and air. Some of the circulating water is entrained as small droplets by the air stream in the fill. Most of these are removed by drift eliminators placed downstream of the fill. The few droplets leaving the tower are referred to as "drift" and are currently controlled to about 0.0005% of the circulating water flow with modern, high efficiency drift eliminators. Drift rates from older, existing installations are more typically in the 0.001% to 0.002% range.

Make-up water must be withdrawn from the water source and added to the recirculating water loop to replace the water lost as evaporation, blowdown and drift. The additional make-up required to replace blowdown is a strong function of the make-up water quality, which sets the amount of blowdown required to maintain acceptable levels of dissolved solids for control of scaling, fouling and corrosion. The total make-up water required is a small fraction (typically 2% to 10%) of the water that would be withdrawn from a waterbody for once-through cooling.

2.3.2 Wet Cooling Towers - Natural-Draft

Wet natural-draft cooling towers operate on a similar principle to mechanical-draft towers, except that the natural buoyancy effect of heated air, rather than fans, is used to draw air into contact with water. They are designed as a single large hyperbolic shaped tower as shown in figure 2-5.

The tower is open at the top and at the base. This design creates a natural draft as the hot circulating water heats the air, increasing the buoyancy, and causing it to flow out the top of the tower while cooler ambient air is drawn in at the base of the tower. As a result, these towers avoid the need for extra electric power to operate the fans used to induce air flow in mechanical draft towers. The capital cost to construct the large hyperbolic tower is greater than the cost of mechanical draft towers. However, the operating cost is reduced and generation output is increased compared to mechanical draft towers, since there are no fans. The economic trade-off often makes natural-draft towers a preferred choice for large, baseloaded plants. For this reason they were frequently used on nuclear plants.

From an environmental standpoint the greater height of the tower helps to reduce issues associated with icing, fogging and particulate deposition but increases potential aesthetic impacts.

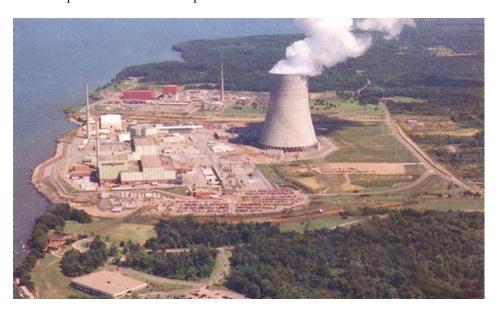


Figure 2-5
Counterflow, natural draft cooling tower

2.3.3 Helper Towers

Some plants have added cooling towers to an existing once-through cooled system without converting to a closed-cycle system. This modification is typically used during hot summer months to help reduce cooling water temperatures to below permit limits before discharge back to the source waterbody. Adding "helper towers" for this purpose typically does not modify the once-through intake system, including the CWIS and inclusive screen systems. The once-through cooling flow rates remain unchanged. The only difference is that heated water flowing out of the condenser is pre-cooled by towers before discharge to the source waterbody. Six nuclear plant sites use helper towers in the summer. All but one of these uses mechanical-draft helper towers; one uses hyperbolic helper towers.

2.3.4 Dry Cooling Towers

Dry cooling systems reject the heat of condensation directly to the atmosphere with no consumptive use of water in much the same manner by which an automobile radiator cools the hot water from the car engine. Systems for power plant applications are of two types, called "direct" dry cooling and "indirect" dry cooling.

2.3.4.1 Direct dry cooling

In direct dry cooling systems, low quality steam is routed from the turbine exhaust directly to air-cooled condensers (ACCs) through a series of ducts and risers. The ACC consists of a number of "cells." Each cell is of an A-frame construction with bundles of finned tubes sloping down from a steam duct at the top to a condensate collection line at the bottom. In the bottom of each cell is a large, axial flow fan which draws air from the surrounding atmosphere and forces it across the tube bundles to absorb the heat from the condensing steam. The individual cells are arranged in rows (streets) along a common steam duct; typically with several streets, each with its own steam duct, arranged in parallel.

The ACC is sized to maintain a certain steam condensing temperature and corresponding turbine exhaust pressure for a given total steam flow at a given ambient air temperature. Typically sized ACCs have an initial temperature difference (ITD), defined as the steam condensing temperature minus the ambient air temperature, of around 40°F. Therefore, in hot arid regions where the ambient temperature can reach 110°F or higher this corresponds to a condensing temperature of 150°F and a corresponding turbine exhaust pressure of around 7.5 inches Hga.

When compared to a typical design point with wet cooling systems discussed in the previous paragraph, plant performance will be lower with dry cooling as a result of the higher backpressure. Because of the higher back pressure, a different turbine design capable of operating well above traditional exhaust pressures is required. Furthermore, for plants of equal capacity an ACC will:

- have a larger footprint than the comparable wet cooling tower
- be significantly more expensive than the comparable wet cooling system including both the cooling tower and the surface condenser
- consume more operating power for the ACC fans than do the pumps and fans for a wet cooling system.

Many of these installations are on fossil plants in hot, arid sites, as seen in Figure 2-6, where sufficient cooling water to support wet cooling was simply not available; others have been installed at fossil sites near large water bodies, as shown in Figure 2-7. Such installations were motivated by a variety of reasons including avoiding the environmental effects of aqueous discharge or impingement/entrainment on the source waterbody or the elimination of cooling tower plumes and drift and potential icing particularly in the vicinity of airports, highways or densely populated urban areas. These applications are designed for the higher condenser backpressure and reduced efficiencies associated with dry cooling.



Figure 2-6 Air-cooled condenser at Higgins Energy Center



Figure 2-7 Air-cooled condenser at Mystic Power Station

2.3.4.2 Indirect dry cooling

Indirect dry cooling systems typically consist of a conventional shell-and-tube surface condenser and an air-cooled heat exchanger (ACHE) (not a condenser)

in which the hot cooling water from the surface condenser is cooled (not condensed) in finned tubes, over which ambient cooling air is blown by large fans. In concept, the indirect dry system is similar to the closed-cycle wet cooling system where the wet cooling tower is replaced with the ACHE. In this case no water is consumed in the process, and no water is withdrawn from, or blown down to, the environment.

Indirect dry cooling is more costly (with the addition of a surface condenser and circulating water pumps), and has a greater adverse effect on plant performance than direct dry cooling. This is a result of the terminal temperature difference of the surface condenser, the circulating water pumping power requirement through the ACHE, and lower temperature differential on the ACHE. Currently, no plant in the US uses indirect dry cooling for the full cooling capacity. A single fossil plant installation from the 1970's (San Juan Generating Station Unit 3) was designed to provide significant water conservation with a large air-cooled section mounted above the wet cells. However, the tube bundles have been severely damaged by condensate freezing, and to date, this approach has not been used elsewhere. A number of wet cooling towers have a small dry heat exchanger at the top of the tower for purposes of plume abatement, but they provide little (~5%) reduction in water withdrawal or consumption compared to conventional wet cooling towers.

2.3.4.3 Dry cooling-retrofit considerations

All dry cooling systems to date have been installed on new plants which were specifically designed to accommodate the operating constraints imposed by dry cooling, such as using turbines which can operate at elevated exhaust pressures in the range of 8 to 10 inches Hga. Retrofitting existing plants from once-through cooling or even closed-cycle wet cooling to dry cooling would introduce significant difficulties. Existing turbines are normally limited to operation at exhaust pressures in the range of 4 to 5 inches Hga. At some hot sites, dry cooling would be unable to achieve these condensing pressures at any reasonable size and cost, thus requiring either changing out the turbine as part of the retrofit or incurring significant load reductions on the hot days when energy demand is generally the greatest. Even at cooler sites where allowable backpressures could be maintained for most of the year, the ability to duct turbine steam from inside the existing turbine hall to the ACC located outside is often extremely difficult and costly. In addition, since the steam ducts must be kept relatively short to minimize steam duct pressure drop, the ACC must be located close to the plant building. The large height and footprint of an ACC can make it impossible to find an acceptable area in which to place the equipment.

In recognition of these issues, EPA rejected the option to require dry cooling from consideration in the current rulemaking for existing plants. (See Section 2.6 for discussion of rulemaking.)

2.3.5 Hybrid Wet/Dry Cooling Towers

The term "hybrid cooling" refers generically to a cooling system with both wet and dry cooling elements. Either or both are available for handling the plant heat load as conditions dictate. The wet and dry elements can be integrated in a single structure or arranged as separate structures operating in series or parallel. Also, hybrid systems can be designed with the objective of either plume abatement or water conservation. The towers in which the dry and wet elements are integrated in a single tower structure have typically been designed for plume abatement although a few have been built with significant water-conserving capability.

2.3.5.1 Integrated hybrid tower—plume abatement

Plume abatement towers are essentially all-wet systems that employ an air-cooled heat exchanger in series with the wet tower. While the dry section rejects some portion of the heat load and, therefore, provides some amount of water conservation, it is typically less than 5%. The primary function of the dry section is to provide a flow of heated dry air which can be mixed with the saturated exhaust plume from the wet portion of the system. This results in a tower exhaust plume in which the psychometric conditions are above the point of saturation during those cold, high-humidity periods of daytime operation when the plume from an all-wet cooling tower is likely to be visible. These towers can also be used to reduce fogging or icing of nearby runways or roadways.

2.3.5.2 Integrated hybrid tower-water conservation

The only example of an operating integrated hybrid tower providing significant water conservation exists on Unit 3 of the San Juan Generating Station, a fossil plant in San Juan, New Mexico. It consists of a conventional shell-and-tube steam condenser coupled to a hybrid tower with an air-cooled dry section on top which discharges into a wet cooling tower beneath and was designed to use only 30% of the water required for all-wet cooling. A schematic of the system is shown in Figure 2-8.

As noted previously, this design has not been replicated in the U.S., although a few units using a similar approach have used in other countries. Hybrid cooling for water conservation in the U.S. has predominantly been implemented with a parallel system with separate wet and dry elements.

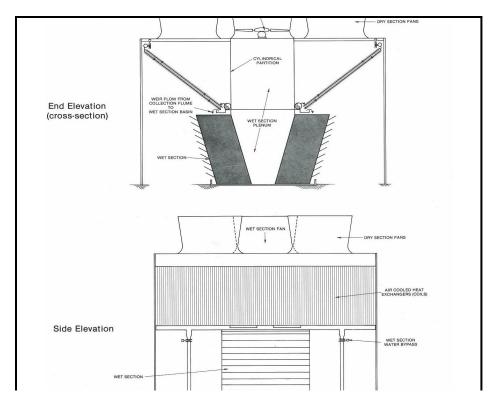


Figure 2-8
Schematic of integrated water-conservation tower

2.3.5.3 Hybrid (parallel wet/dry) cooling

The more common approach to hybrid cooling is the so-called "parallel wet/dry" system consisting of separate cooling circuits---one dry and one wet---operating in parallel. The arrangement is shown schematically in Figure 2-9.

This system has the capability to split the steam flow and, hence, the cooling load between the dry element, consisting of an ACC, and the wet element, consisting of a surface condenser coupled with a wet cooling tower. The system is self-balancing and the division of the heat load between the wet and the dry elements is determined by ambient conditions. When the ambient temperature drops low enough so that the full heat load can be handled by the ACC at an acceptable turbine exhaust pressure, the wet system can be shut off. The annual water requirement is determined by the relative design capacity of the wet and dry elements, meteorological conditions, and operational goals. Typical design points result in annual water use of between 20% and 80% of that required for an all-wet system.

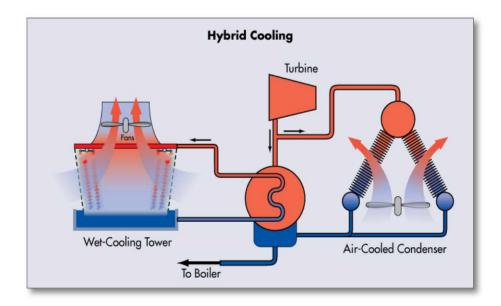


Figure 2-9 Schematic of parallel, wet/dry cooling system

Hybrid cooling can overcome some of the drawbacks of all-dry cooling, such as the hot day performance penalty on plant output while still achieving significant water savings. The wet element can be sized to minimize or even eliminate the problem of elevated turbine exhaust pressure on the hottest day. However, the cost is still significantly higher than wet cooling and may approach that of all-dry cooling, depending on the annual water availability.

Retrofit considerations, other than the turbine exhaust pressure issue, are similar to those for all-dry cooling with regard to the difficulties of ducting the steam to the ACC and in finding a satisfactory place to locate the ACC close to the turbine building.

2.3.6 Cooling Ponds

Cooling ponds are constructed ponds large enough to provide condenser cooling water without the need for a cooling tower. Such ponds are most common in more arid parts of the country. Once the pond is constructed it is normally filled from a nearby river during periods when there is adequate stream flow. The same source is typically used to replenish the evaporative loss or drainage into the soil.

As discussed in the next chapter, over 15% of U.S. reactors use cooling ponds. Cooling ponds require a significant amount of land, and are not feasible in many topographical situations or in areas where groundwater could be affected. Although typically more expensive up-front (constructing a man-made pond or lake is typically more expensive than erecting cooling towers), the cooling pond has the advantage of transferring a larger percentage of waste heat to the atmosphere via convection, radiative heat transfer, and lower evaporation rates due to lower differential temperatures relative to cooling towers, thereby reducing the rate of evaporation and thus reducing the rate of consumptive water loss. In

contrast, virtually all of the heat transfer from a cooling tower occurs by rapid evaporation (with its associated higher moisture content and higher rate of water loss). Cooling pond systems maintain the large flow rates associated with once-through cooling, but because these cooling ponds are dedicated to plant cooling, their environmental impacts are typically much less. Some nuclear plants are sited on cooling ponds that are man-made, and not considered "waters of the U.S." As such, they are considered water treatment ponds and therefore are exempt from aquatic life and thermal discharge regulations. These plants are identified in Chapter 3 as "Situation 1B" and are listed in Appendix B. Additionally, as a result of post 9-11 security requirements, access restrictions for fishing on cooling ponds have increased.

2.4 Dry Cooling for Nuclear Power Plants

To date, dry cooling has not been considered a viable option for nuclear power plants. There have been only two dry cooled nuclear plants built anywhere in the world, and none in the U.S. One of these was a small (~100MWe) nuclear plant at Schmehausen, Germany using an indirect dry system with an innovative natural-draft tower design. The plant no longer operates. The second is a very small four-unit plant at Bilibino in northern Siberia, built in the 1970s. The four small units, only 12 MWe each, provide district heating plus some electrical power to the area. Dry cooling was selected because the plant is located in permafrost where flowing water is problematic. The plant design is unlicensable in the U.S. and is scheduled for decommissioning later this decade.

There are six impacts that make it difficult to use dry cooling on modern, full-scale nuclear units:

- 1. Efficiency: Dry cooling systems are extremely inefficient in comparison to water cooling. Three factors contribute to this:
 - Turbine output loss with increasing exhaust pressure: Steam turbines suffer a loss in output at constant steam flow if the operating exhaust pressure exceeds the design exhaust pressure. Dry cooling systems usually have a higher steam condensing temperature (and corresponding higher turbine exhaust pressure) for the same steam flow and a slightly higher cooling system heat load at the same ambient conditions.

Dry cooling with an air-cooled condenser is typically sized to produce a condensing temperature that is 35°F to 45°F above the ambient dry bulb temperature. Closed-cycle cooling systems are systems are limited by the ambient wet bulb temperature. For a closed-cycle system with a mechanical-draft, wet cooling tower, the condensing temperature would be expected to be 30°F to 40°F above the ambient wet bulb temperature during the hottest periods, rising to 50°F to 60°F above wet bulb during the colder periods of the year.

At any relative humidity below 100%, the wet bulb temperature is less than the dry bulb temperature. Depending on the climate at the site, the average difference between the dry bulb and wet bulb during the summer months can range from 10°F to 20°F and the maximum difference at the hottest hours can exceed 50°F. Therefore differences in turbine exhaust pressure can range from 2 to 5 inches Hga at design conditions. Depending on the turbine type and design, this can represent a 5 to 10% reduction in gross output. On average, over the course of a year the difference is less, typically ranging from 1 to 2%. Turbine output loss would be even greater when compared to the more efficient oncethrough cooling system option.

- Required reduction in steam flow to protect the turbine: The operation of any steam turbine is limited to a design maximum exhaust pressure to avoid damage to the last stages of blading. Turbines are normally equipped with a warning system which alarms at some backpressure and then trips at some higher backpressure. Typical values for turbines selected for units intended to be equipped with once-through or closedcycle wet cooling would have a design backpressure of 1.5 inches Hga (for most once-through systems) to 2.5 inches Hga (more typical for closed-cycle wet systems). Both would typically have an alarm point around 4 inches Hga and a trip point of about 5 inches Hga. If the unit is intended to be equipped with dry cooling, the likely turbine selection would be an "extended backpressure" turbine with a design point of around 2 to 3 inches Hga but an alarm of 7 to 7.5 inches Hga and a trip point of 8 inches Hga. Some recent installations have turbines that can operate at 9 to 10 inches Hga. If the operating point approaches the alarm point, it is normal procedure to reduce the steam flow to the turbine to reduce the exhaust pressure to a more comfortable level. Depending on the reduction required this can reduce the turbine output proportionally and can amount to perhaps a 15% to 30% reduction in turbine gross output for a short time.
- Higher operating power requirements with dry cooling: The operating power requirements for a dry cooling system (fans on the air-cooled condenser) are typically higher than the operating power requirements for a wet cooling system (cooling tower fans and circulating water pumps) for the same steam flow and cooling system heat load and ambient conditions. This additional operating power reduces the net output of the unit. The magnitude of this difference varies with system design and site characteristics but can be 0.5% to 1.5% of plant output for a closed-cycle cooled plant. This difference is even larger when compared to a once-through cooled plant, in the 3% to 6% range.

The higher efficiency penalties occur on the hottest days of the year, when electricity demand is the highest, power prices are the highest, and when replacement power may not be readily available. [Ref. 1]

2. <u>Turbine design:</u> Nuclear plant turbines suffer more from increased backpressure than do fossil turbines. First, the nuclear steam cycle operates at high pressure turbine inlet temperatures and pressures that are lower than fossil units and, as a result, changes in exhaust conditions represent a greater percentage change in the energy that can be extracted from a steam flow operating between the two end points. EPRI is not aware of any

manufacturer that offers a nuclear turbine design for extended or elevated backpressure operation, as typically required for turbines at dry cooled plants. All existing plants designed, built and operated on either once-through or closed-cycle wet cooling are equipped with turbines with 4 to 5 inches Hga alarm/trip points. For even very large air-cooled condensers, these limits would be exceeded at ambient temperatures above 100°F. Therefore, at most sites there would be a number of occasions each year where steam flow would have to be reduced. At many sites, temperatures above 100°F can occur for hundreds of hours a year.

- 3. Cost: Dry cooling is cost-prohibitive as a retrofit to current plants. EPA has acknowledged this option as impractical in both its Phase I rulemaking and its current rulemaking. For new plants, dry cooling is always evaluated as an option, but has been rejected consistently during the licensing process (see expanded discussion below). Note that direct dry cooling is currently not an option for nuclear plants (for safety and regulatory reasons), and that the indirect dry cooling alternative is much more expensive, as discussed above, in terms of both capital and operating costs.
- 4. <u>Land use</u>: Dry cooling requires large amounts of open land directly adjacent to the reactor to install.³ As a retrofit on current plants, many existing sites could not physically accommodate dry cooling.
- 5. Licensing and safety: Direct dry cooling, with an open, uninterrupted path from the ACC steam duct back to the steam generating elements of the reactor presents significant licensing challenges for nuclear safety reasons. There are a number of transient scenarios (e.g., loss of feedwater, turbine trip) for which all nuclear plants must be able to demonstrate ample safety margins, for which direct dry cooling would not satisfy regulatory requirements. Transients such as a loss of offsite power are more benign if post trip "decay heat" can be dissipated to a water-cooled condenser. Dry cooling, with its lower thermal mass, would limit the rate of this heat removal and could lead to higher temperature or pressure transients in the reactor as a result. Another hypothetical scenario of concern would be a leak in ACC finned tubes, which could allow direct escape of reactor steam to the environment under some scenarios. Reactor steam is slightly radioactive in Boiling Water Reactors (BWRs), with most of the radiation coming from N-16 decay with a very short half-life (seven seconds). In Pressurized Water Reactors (PWRs), if direct dry cooling is used, a hypothetical primary to secondary leak could release radioactivity into the secondary circuit, allowing small amounts of radioactivity in the turbine exhaust steam. (This is not a concern if indirect dry cooling is used.) In both BWRs and PWRs, releases to the atmosphere via a leak in an ACC finned tube would lack the filtering capability of a water-cooled condenser. These releases would be small, and insignificant from a public health and safety perspective. However, they could be significant in licensing calculations and safety analyses of

³ Calculations performed for desert regions (e.g., Arizona) indicate the energy penalty could be 30% or greater. One plant calculated a land requirement for dry cooling at its site of the equivalent of about ten football fields.

- hypothetical accident scenarios, and might be significant enough to show up in a probabilistic risk analysis as a negative for dry cooling. For these reasons, it is unlikely that a large nuclear plant would rely exclusively on dry cooling.
- 6. Transient conditions: ACCs can suffer reliability problems caused by wind gusts, which cause transients in the heat removal rate from the ACC. These rapid changes in cooling capacity could be sufficient to initiate unplanned reactivity changes or even a reactor transient. This in turn would likely introduce new licensing issues that would require NRC review and approval.

Note that utilities with some flexibility in both new plant siting and technology options for available sites are more likely to consider nuclear generation for sites with adequate cooling water resources, and more likely to consider non-nuclear technology options (e.g., NGCC) for sites with poor water resources, especially sites requiring dry cooling. In fact, most of the dry cooled plants in recent years have been gas-fired combined-cycle plants. For these plants, typically equipped with relatively small steam turbines (175 to 250 MW), extended backpressure designs are common and dry cooling can be more easily accommodated.

New plant Combined License Applications (COLAs) evaluate all options for heat dissipation. In theory, dry cooling is relatively more feasible for new generating plants, than as a retrofit on existing facilities because accommodations could be designed into the plant to address some of the above issues. In the nuclear area, some small advanced reactor concepts being developed today are considering dry cooling as an option for selected market applications. However, none of the planned deployments of standardized "GEN III+" Advanced Light Water Reactors (ALWRs) will use dry cooling. All new plant COLAs submitted to NRC to date have rejected dry cooling as infeasible for the site or uneconomical because of lost electrical generating efficiency and significantly higher capital and operating costs. It is likely that new nuclear plant applications for the foreseeable future will continue to favor sites that allow for sufficiently reliable and long-term assured water resources, thereby avoiding the reliability, efficiency and cost penalties associated with dry cooling.

For similar reasons, EPA rejected the option to require dry cooling technology in both its Phase I rulemaking for new facilities (2001) and its current rulemaking for existing facilities. In its proposed rule [Ref. 2], EPA states: "Dry cooling is not demonstrated and available for nuclear facilities, due to the backup cooling systems and related safety needs required at a nuclear facility."

2.5 Hybrid Cooling for Nuclear Power Plants

The use of hybrid cooling on nuclear plants faces the same question of the acceptability of using ACCs as was discussed for all-dry cooling. All the hybrid systems to date have been used on fossil plants, either coal-fired steam plants or gas-fired, combined-cycle plants. The parallel arrangement using an ACC has been the preferred design in all cases. For nuclear plants, hybrid systems have

⁴ Federal Register, Vol. 76, No. 76, April 20, 2011, pg. 22200.

been proposed. For example, the cooling system for Dominion's planned North Anna Unit 3 uses a series arrangement with the ACHE in service during drought periods. The use of a hybrid tower with a wet cooling tower and ACHE can be arranged in either series or parallel. However, the capital cost and operating power requirements of this approach are both significantly higher than those for a hybrid system with an ACC as the dry element.

Despite the issues discussed earlier related to total reliance on dry cooling, the use of dry cooling to augment a cooling system that relies primarily on wet cooling is technically feasible for a large nuclear plant. Some new nuclear plants are considering the addition of a small amount of indirect dry cooling to enable a "plume abatement" capability in a mechanical-draft cooling tower. ⁵ The small amount of dry cooling used to provide this function is sufficient to eliminate the visible plume exiting the tower, and also helps reduce water consumption rates. These plume abatement systems do not pose a safety concern.

A hybrid system with dry cooling could also be used to compensate for either water supply limitations or discharge temperature limitations during drought conditions or summer heat waves. For example, Dominion has analyzed drought scenarios for its planned North Anna Unit 3, and has opted to include in the design a closed-cycle, combination dry and wet (hybrid) cooling tower system. This system includes a wet mechanical tower with an air-cooled dry section for water conservation, with make-up water supplied from Lake Anna, and a separate dry tower that can be brought on-line in specific circumstances. The make-up water to the wet tower will replace water lost from the operation of the wet tower, including losses from evaporation, blowdown, and drift. The hybrid cooling tower system will have two modes of operation, Maximum Water Conservation (MWC) and Energy Conservation (EC). In the MWC mode, a minimum of 1/3 of the heat is rejected from the plant via dry cooling. In the EC mode, the dry tower fans are turned off, and 100% of the heat is rejected in the wet tower (normal closed-cycle cooling). The dry section of the (hybrid) wet tower continues to operate to conserve water.

A variation of the hybrid tower (different than the North Anna-3 design) would use a dry section above the wet tower section where cooler outside air is drawn in through ducts while the warm moist air from the wet section exhaust passes over the outside of the ducts. Water from the wet section exhaust condenses on the cooler dry section duct surfaces and falls back into the process stream before leaving the cooling tower, thereby reducing the water loss due to evaporation.

Nuclear power plants may also consider non-traditional water sources, if available. This option is discussed in a later section. Advanced reactor designs that are technically and economically more compatible with the use of dry cooling (e.g., High Temperature Gas Reactors, or HTGRs), might be the best option for future generations of nuclear units with water constraints.

⁵ Hybrid wet/dry cooling towers are sometimes designed for plume-abatement such that the cooling towers are capable of operating without a visible plume by using a combination of dry and wet cooling. See COL applications for North Anna-3 & Calvert Cliffs-3 for details.

2.6 Overview of the Clean Water Act Relative to Once-through Cooling

The Clean Water Act regulates the discharge of heat into the environment, as well as the withdrawal of cooling water into a cooling water intake structure. This Section provides a summary discussion for each.

2.6.1 Thermal Discharges

Heat is regulated as a pollutant under the Clean Water Act (CWA) and water quality criteria have been established to limit the discharge of waste heat. Regulations governing waste heat discharge by power plants are implemented as part of the National Pollutant Discharge Elimination System (NPDES) regulatory program administered by the EPA. In most cases administration authority has been delegated to the states. Allowable mixing zones are generally established based on waterbody type. Thermal plume dimensions are set to ensure safe passage of fish and aquatic life and therefore limits are sometimes set on the cross sectional area to allow safe fish passage. Limits may also be set on the amount of contact with the waterbody substrate to protect benthic organisms. Due to tidal movement in both directions, limits are often set based on a tidal prism in estuaries.

The CWA recognizes that heat is somewhat unique as a pollutant in that it is a physical rather than chemical change in receiving waters and causes a temporary change in water condition. This has resulted in a unique variance provision for thermal discharges under §316(a) of the Act. This provision allows a facility to exceed the water quality criterion if the facility can demonstrate that the "alternate effluent limit" will ensure protection of a balanced population of fish and other aquatic life in and on the waterbody. A number of nuclear facilities rely on a §316(a) variance; further discussion on this topic is found in Section 6.1 of this report.

2.6.2 Cooling Water Intake Structures

Section 316(b) was included as part of the 1972 Clean Water Act amendments. The statutory provision required that "the location, design, construction and capacity of cooling water intake structures reflect the best technology available (BTA) for minimizing adverse environmental impact." EPA first issued regulations to implement this statutory requirement in 1976. However, those regulations were challenged and remanded back to EPA by the Fourth Circuit Court in 1977 on procedural grounds. As a result of litigation in 1993, EPA initiated work on a new rule and subsequent to a consent decree, set a schedule for trifurcation of the rulemaking into three phases; specifically, Phase 1 would address New Facilities; Phase II would address existing power plants above 50 million gallons per day MGD of cooling water; and Phase III would address existing power plants not covered by Phase II and other industrial facilities.

The Phase II rule addressed existing power plants that used in excess of 50 MGD. The Phase II regulations were issued on July 9, 2004 [Ref. 3]. These

regulations were challenged by a number of environmental stakeholder organizations and industry, and the case was heard by the Second Circuit Court. The Court determined that use of restoration measures and the Cost-Benefit Test could not be used as compliance options. More importantly, the Court said that EPA based its determination that closed-cycle cooling was not BTA for existing facilities at least in part, due to the cost of the technology relative to the environmental benefits. The Court pointed out that consideration of the environmental benefits was not allowed for the Phase II Rule. The Court remanded this determination back to EPA for clarification. The Court clarified that EPA could consider factors that included industries' ability to bear the cost, impacts to energy production and efficiency and adverse impacts associated with retrofits in making this determination.

As a result of the Decision, the industry filed a petition for Certiorari with the Supreme Court for review of the Decision on the use of restoration and consideration of cost relative to benefit. The Supreme Court would not consider the Second Circuit's decision on use of restoration, but did agree to review the issue of cost in making the BTA determination, and issued its determination on April 1, 2009. The Supreme Court upheld EPA's authority to consider cost relative to the benefit in making the BTA determination to the extent it wished to do so. Based on the Second Circuit and Supreme Court Decision, EPA withdrew the 2004 regulations and engaged in a new rulemaking, and proposed regulations for existing facilities that were published on April 20, 2011 [Ref. 2]. The proposed rule incorporated the scope of the prior Phase II Rule plus the Phase III Rule.

EPA's proposed rule applies to all facilities (both thermoelectric and manufacturing) that use over 2 MGD of cooling water. The agency considered four options for the proposed rule that are summarized as follows:

Option 1 - The preferred option established separate requirements for existing once-through cooled facilities and new units at existing facilities. Closed-cycle cooling was proposed as BTA for new units at existing facilities. Requirements for new facilities are generally very similar to those in the Phase I Rule for new facilities. For existing electric power generating units, EPA proposed BTA separately for impingement and entrainment. Impinged organisms are defined as those that cannot pass through a 3/8-inch mesh sieve (i.e., screen) while entrained organisms are those that would pass through a 3/8-inch mesh sieve. EPA proposed two alternatives for impingement compliance. In Alternative 1, BTA for impingement is based on modified traveling screens with a fish return for finfish. Facilities choosing this option must reduce impingement mortality by 69% monthly and 88% annually, to be verified by biological monitoring. In Alternative 2, facilities must not exceed a through-screen velocity of 0.5 feet per second (fps). BTA for impinged shellfish in tidal waters is based on the reduction that can be achieved by a properly deployed and maintained barrier net. There are additional requirements to address fish entrapment that may be an issue for some facilities.

For entrainment, BTA is to be determined by the permitting authority on a case-by-case basis for all facilities withdrawing more than 125 MGD actual intake flow (AIF). Such facilities are required to submit peer reviewed information on all life stages of entrained species, the cost and performance of technologies to reduce entrainment (including both closed-cycle cooling and alternative entrainment reduction technologies and operational measures), environmental impacts resulting from technologies, the benefits of technologies and any impacts of technologies to regional electric supply. Facilities withdrawing between 2 MGD design intake flow (DIF) and 125 MGD AIF are not required to submit the peer reviewed information but are also potentially subject to entrainment requirements on a case-by-case basis.

Option 2 – The same Option 1 requirements apply for new units at existing facilities under Option 2. Also, the same Option 1 requirements apply for impingement mortality reduction for all facilities withdrawing more than 2 MGD. However, flow reduction commensurate with closed-cycle cooling is BTA for all facilities that withdraw more than 125 MGD DIF. In addition, the entrainment reduction information requirements for Option 1 do not apply since closed-cycle cooling is designated as BTA.

Option 3 – The same Option 1 requirements apply for new units at existing facilities as well as the Option 1 requirements for impingement mortality reduction. However, for this option, closed-cycle cooling is designated BTA for all facilities that withdraw more than 2 MGD.

Option 4 - The same Option 1 requirements apply for new units at existing facilities. For impingement mortality, the uniform Option 1 requirements would only apply to facilities that withdraw 50 MGD or more of cooling water. Facilities using between 2 MGD and 50 MGD DIF would be subject to impingement reduction requirements on a case-by-case basis and all facilities withdrawing more than 2 MGD would be subject to entrainment reduction requirements on a case-by-case basis.

In summary, closed-cycle cooling was established as BTA for new units at existing facilities under all four options. For existing units, closed-cycle cooling for entrainment could be required on a case-by-case basis for all facilities over 2 MGD under Options 1 and 4. For Options 2 and 3, closed-cycle cooling is BTA for facilities using more than 125 MGD AIF and 2 MGD DIF, respectively. Impingement mortality reduction is required under all four options but is based on compliance using options other than closed-cycle cooling.

For nuclear plants, all of which withdraw much more than 125 MGD, these options can be more simply summarized as follows: Option 1 (the recommended option) proposes a one-size-fits-all national standard for impingement mortality, along with some flexibility in addressing entrainment. Options 2 and 3 would effectively mandate closed-cycle cooling for all nuclear facilities.

The EPA recommended option in the 2011 proposed rule for existing facilities at existing sites allows for some flexibility in selecting the "best technology available

(BTA)" in the case of entrainment (requirements for impingement mortality reduction under the recommended option are limited and could be very costly). For entrainment, the NPDES permitting authority is required to consider nine environmental and social factors in choosing a "best technology available:"

- 1. Number/types of organisms entrained
- 2. Entrainment impacts on the waterbody
- 3. Quantified and qualitative social benefits and social costs of available entrainment technologies, including ecological benefits and benefits to any threatened or endangered species
- 4. Thermal discharge impacts
- 5. Impacts on the reliability of energy delivery within the immediate area
- 6. Impacts on changes in particulate emissions or other pollutants associated with entrainment technologies
- 7. Land availability inasmuch as it relates to the feasibility of entrainment technology
- 8. Remaining useful plant life, and
- 9. Impacts on water consumption.⁶

Some of these factors may limit the use of cooling towers. For example, if mandating cooling towers would result in an unacceptable impact on water consumption, or if there is insufficient land available for cooling towers, or if the particulate emissions from the cooling tower exceed regional limits under the Clean Air Act, then the permitting authority could determine that an existing facility would be allowed to continue using once-through cooling, as long as other aquatic life protection features (e.g., wedge-wire screens, deep water intakes) can serve as "best technology available." If there is no alternative fish protection technology to reduce entrainment for which the permitting authority deems the benefit is not significantly greater than the cost, then the permitting authority could determine that the existing cooling water intake structure is BTA for entrainment.

However, if a new unit is added to that same existing site, the proposed rule would likely require the new reactor to use closed-cycle cooling, even if that site possesses identified and acknowledged disqualifying factors that make cooling towers unacceptable for the existing facility units. Note that the 2001 CWA Phase I rule applicable to new facilities would allow for the use of once-through cooling for new nuclear plants at new (i.e., "greenfield") sites under certain conditions.

The Phase 1 rule allowed for expedited approval for closed-cycle cooling ("Track 1") and a "Track 2" or "demonstration track" approach that requires any combination of design measures, technologies and operating methods to reduce

⁶ Federal Register, Vol. 76, No. 76, April 20, 2011, pg. 22288.

adverse environmental impact to a level comparable to that which would be achieved under Track 1. The EPA defined "comparable" as reductions of both impingement mortality and entrainment to 90% or greater of the Track 1 reduction. The Track 2 approach requires a Comprehensive Demonstration Study (CDS) that must be submitted to the permitting authority along with the NPDES application that evaluates all the options the facility intends to use.

Section 3: Nuclear Facility Database and Specific Considerations

3.1 Application of Once-through Cooling versus Closed-cycle Cooling in the U.S.

3.1.1 Overview of U.S. Nuclear Facilities

Currently, 104 reactors are licensed for commercial generation of electricity by the U.S. Nuclear Regulatory Commission (NRC). These reactors operate on 65 sites in the U.S. in 31 states. Worldwide, there are about 450 reactors operating in over 30 countries, supplying about 15% of global electricity production. 60% of all world reactors are licensed to operate in the U.S., France, and Japan.

Regarding cooling system design details and siting situations in the U.S., the following groupings were identified in "Cooling Water Issues and Opportunities at U.S. Nuclear Power Plants" (Dec. 2010, Ref. 4), and are repeated here in this report, with data updates as necessary.

Key summary data are provided below. They are based on details in Attachments A, B, and C, which are spreadsheets that provide the following nuclear plant data for the United States:

- Attachment A: Listing of all currently operating reactors (104) and planned reactors with Combined Operating License Applications (COLAs) or Early Site Permits (ESPs) on file with NRC, organized by U.S. Geological Survey (USGS) water resource regions, along with other relevant data (operator/licensee, State, cooling water source basics, cooling system basics, condenser flow rate, reactor type/NSSS supplier, summer capacity, thermal output, and operating license issuance date). In addition to the 20 COLAs that are under active NRC review, Attachment A also lists other new plants with only announced plans for future submittals, prior submittals with NRC review currently suspended, and Watts Bar Unit 2 construction completion. See Figure 3-1 and Table 3-3 at end of this section for details on USGS resource regions.
- Attachment B: Breakdown of the existing 65 U.S. nuclear power plant sites, organized by cooling water "situation." Additional site information in this table includes, for example, cooling water source description, site size (acres), intake structure location and design, and discharge structure location and

- design. New plant data are also displayed, including initial data on four "greenfield" sites, which add to the 65 existing sites.
- Attachment C: Summary tabulation of the number of NPPs in each cooling water situation, organized by the groupings in Attachment B, on both an individual reactor basis and a plant site basis. Data are also broken down by current plants and new plants in these categories.

The summary table below lists the number of plant sites in each cooling water situation, along with various comments and clarifications. For simplicity, only current plant sites and reactors are included in Table 3-1 below. New plant data are included in Attachments A, B and C.

Table 3-1 Number of U.S. Nuclear Plant Sites, Organized by Cooling Water Situation

Situation Number	Situation Description	Number of Sites	Number of Reactors
1A	Site uses wet closed-cycle cooling towers <u>at all</u> reactor units on that site (natural draft, mechanical or combination)	22	32 (+2)*
1 B	Site uses once-through cooling on a man-made cooling pond that has been judged to <u>not be a</u> "waters of the U.S." and thus exempt from EPA's CWA § 316(b) requirements. These sites are treated under the CWA as <u>functionally equivalent to closed-cycle cooling tower plants</u> (Situation 1A above)	4	8
2	Site uses once-through cooling on a man-made cooling pond that has been judged to be "waters of the U.S." and thus <u>not</u> exempt from EPA's CWA § 316(b) requirements.	7	10
3	Site uses once-through cooling on a multi- purpose reservoir (in-line with source river)	7	15 (-1)*
4	Site uses once-through cooling on an ocean, or bay that is open to the ocean (i.e., with ocean salinity levels)	7	11
5	Site uses once-through cooling on an estuary or tidal river	6	11
6	Site uses once-through cooling on a freshwater river (free flowing)	6	8
7	Site uses once-through cooling on a Great Lake	6	9 (-1)#
TOTALS		65	104

^{*} Two sites with both a closed-cycle cooled unit and a once-through cooled unit are listed under the applicable once-through category. This applies to Nine Mile Point (Situation 7) and Arkansas Nuclear One (Situation 3), where the older unit is once-through cooled and the newer unit uses a natural-draft cooling tower. When these site data are summed on an individual reactor basis, the data are adjusted to add two reactors to the Situation 1A total and subtract one each from Situations 3 and 7.

It should be recognized that the number of sites in Situations 2-7 are a subset of the total number of sites in each category. For example, the six sites listed for Situation #7 (once-through cooling on a Great Lake) are not the total number of reactor sites on the Great Lakes. Per Attachment A, there are a total of 13 reactors on ten sites on the Great Lakes. Of these ten sites, six are in Situation 7 and four are in Situation 1A. Situation 1A is not broken down by waterbody type.

In order to answer the question, "How many U.S. reactors are once-through-cooled and how many are closed-cycle-cooled, some conventions or "rules" were established. For purposes of this report, the following "rules" are used to classify reactors into the above "situations:"

- The "closed-cycle cooled" category includes all reactors that are cooled exclusively (100%) by either cooling towers (Situation 1A) or a cooling pond that is exempt from § 316(b) requirements (Situation 1B).
- Plants that are cooled by a cooling pond that has not been determined to be exempt from § 316(b) are treated as "once-through."
- Plants that have cooling towers that do not provide all cooling needs at 100% power at all times of the year (e.g., plants with "helper towers" or "seasonal towers") are categorized as once-through. This includes a few plants that use towers extensively for large portions of the year or that have large capacity towers that can provide a majority (but not all) of the required cooling. This "rule" is based on the fact that helper towers typically reduce discharge temperatures but don't reduce flow rate through the intake structure. Note that the EPA's proposed § 316(b) rule considers these plants to be once-through cooling facilities.
- Plants whose condensers are closed-cycle cooled, but that use once-through cooling for small or auxiliary site heat loads (e.g., essential service water) are retained in the "closed-cycle" category. This is reasonable, since the required flow rates for these smaller systems are typically less than the makeup flow rates to a closed-cycle cooling system for the condenser.

Based on these assumptions, cooling categories for the U.S. reactor fleet are summarized here in Table 3-2:

Table 3-2 Summary of U.S. Nuclear Power Plant Cooling System Types

Cooling Mode	Total Reactor Count	Percentage
Once-Through Cooling	62	59.6
Closed-Cycle Cooling	42	40.4
TOTALS	104	100.0

Note that on a site basis (not on an individual reactor basis), the total number of sites in Situations 2 through 7 (once-through cooled sites) is 39. This summation

of once-through sites appears in Attachment C and appears frequently in subsequent chapters in this report.

Following are statistics on types of cooling towers selected for U.S. nuclear power plants:

- Of the 34 reactors in the U.S that use cooling towers (Situation 1A), 20 of them use natural draft cooling towers, 13 use mechanical draft towers, and one (Grand Gulf) uses both.
- Of the 11 reactors that are once-through cooled but use "helper towers," nine use mechanical towers, and two (Sequoyah 1&2) use natural draft towers.
- Of the 26 planned reactors with COL or ESP applications before the NRC, ⁷ 13 reactors plan to use mechanical towers, nine plan to use natural draft towers, and four plan to use cooling ponds exempt from § 316(b) requirements. Two of the reactors planning to use mechanical towers also plan to use municipal effluent for makeup. In addition, Watts Bar-2, currently back under construction, already has a natural draft tower constructed.

3.1.2 Summary of Key Differences between Fossil and Nuclear Facilities

In general, cooling system designs and operations are quite similar between fossil and nuclear facilities. A few subtle differences exist as highlighted below:

- 1. A larger percentage of nuclear plants rely on once-through cooling than is the case for fossil plants. Over 60% of the current fleet of fossil plants in the U.S. uses closed-cycle cooling. In contrast, only 40% of the nuclear fleet uses closed-cycle cooling.
- 2. As discussed in Chapter 5, the water withdrawal and water consumption rates for nuclear plants are slightly higher than for fossil plants. This is because fossil plants operate at higher steam temperatures and pressures and therefore achieve slightly higher cycle efficiencies. The difference in efficiency ranges from 2-3% in relation to coal plants and roughly 10% for gas fired plants. In addition, fossil plants expel some of their waste heat "up the stack."
- 3. All nuclear plants are baseloaded, and because of their low production costs, first to dispatch to the grid. This asset, in addition to nuclear plant's high reliability and performance statistics, results in average capacity factors for nuclear energy in excess of 90%. In contrast, although some fossil facilities have capacity factors similar to nuclear facilities, coal plants operate on average at about a 70% capacity factor, and natural gas/combined cycle plants

⁷ Includes data from three units that have filed COLAs but have subsequently deferred construction, since these filings are still useful in assessing utility choices for preferred cooling tower technology.

at about 50% or less.8 The impacts of this "first to dispatch" status for nuclear plants on cooling water issues are many. Among them are practical limitations on fish protection technologies. As discussed in Chapter 7, there are a number of alternative technologies for minimizing potential adverse impacts on aquatic life, including exclusion devices, traveling screens, diversion systems, relocation of intake structures (e.g., to deeper water or locations further from shore where fish population densities are lower). Some of these technologies are close-to or equally as effective as cooling towers in reducing impingement and/or entrainment, depending on site specific characteristics and affected species. However, some of these alternative technologies involve cooling water flow reductions (variable speed pumps and/or seasonal operations, both of which allow reduced flow or plant shutdown during sensitive periods to aquatic life such as spawning season). These flow reduction strategies are not practical options for nuclear plants, which typically operate at 100% power throughout the year, shutting down for 2-3 weeks every 18 or 24 months for refueling.



Figure 3-1 USGS Water Resource Regionsi

Note: gray lines are state lines, blue lines are major rivers, white lines are water-resources region boundary lines.

⁸ These data are from the latest EIA Annual Report (2010). Anecdotal data suggest that today's natural gas prices are allowing combined cycle plants to dispatch ahead of coal in many parts of the country, suggesting that NGCC could move ahead of coal in capacity factor in 2011 or 2012.

Table 3-3 Number of U.S. Reactors by USGS Water Resources Region

Region #	Region Name	# Operating reactors	# new reactors (w/COLA or ESP)
1	New England	5	-
2	Mid-Atlantic	19	3
3	South Atlantic-Gulf	23	12
4	Great Lakes	13	1
5	Ohio	2	-
6	Tennessee	6	(Watts Bar-2 completion not counted here)
7	Upper Mississippi	15	-
8	Lower Mississippi	3	-
9	Souris-Red-Rainy	_	-
10	Missouri	3	-
11	Arkansas-White-Red	3	-
12	Texas-Gulf	4	4
13	Rio Grande	-	-
14	Upper Colorado	_	-
15	Lower Colorado	3	-
16	Great Basin	-	-
17	Pacific Northwest	1	-
18	California	4	-
19/20	Alaska/Hawaii	-	-
21	Caribbean	-	-
TOTALS		104	20

3.2 Application of Once-through Cooling versus Closed-cycle Cooling Worldwide

3.2.1 Summary of Nuclear Power Plant Data

Data on international application of once-through cooling vs. closed-cycle cooling at current nuclear power plants are presented in Appendix D. These data display a sharp contrast between U.S. regulations and policies and those of other nations. The data not only differentiate between once-through cooling vs. closed-cycle cooling applications, but also differentiate between nuclear plants cooled by fresh water vs. saline water (i.e., plants sited on oceans, estuaries, and tidal rivers (O/E/TRs)). Note that many countries with significant nuclear plants are land-locked, without access to ocean cooling (e.g., Ukraine), while others, like the U.S. and France, have access to both types of cooling. Eight countries rely exclusively on ocean water for once-through cooling of their nuclear plants:

Japan, South Korea, the UK, Sweden, Brazil, Finland, and South Africa. A summary of Appendix D data follows:

Table 3-4 International Data on Use of Once-Through Cooling and Closed-cycle Cooling Modes in Fresh and Saline Water

Nuclear Plants	Fresh Water Closed- cycle cooling	Saline Water (O/E/TR) Closed-cycle cooling	Fresh Water Once- through cooling	Saline Water (O/E/TR) Once- through cooling	
non-US totals, by %	24%	0%	26%	50%	
US totals, by %	39%	1%	39%	21%	

3.2.2 Observations and Insights from International Data

The above data show that the U.S. relies much more on fresh water for nuclear plant cooling and less on saline waterbodies (i.e., O/E/TRs) than other nations, by over a factor of two. The data also show that the U.S. relies much more on closed-cycle cooling and much less on once-through cooling for its nuclear plants than other nations, by a factor of about 1.7. Countries with geographic access to oceans preferentially site thermoelectric plants on O/E/TRs, if available, in large part to take advantage of the cooler water for efficiency reasons, but also to preserve limited and valuable inland fresh water resources for other water users (e.g., municipal water supply, agriculture).

Also note that a recent report by EPA's counterpart agency in the UK [Ref. 5] favors once-through cooling as BTA, even in O/E/TR siting situations: "...the findings of our study indicate that direct cooling can be "Best Available Technology" (BAT) for estuarine and coastal sites, provided that best practice in planning, design, mitigation and compensation are followed." ... "We therefore conclude that direct cooling may be the best environmental option for large power stations sited on the coast or estuaries, subject to current best planning, design and operational practice and mitigation methods being put in place, and meeting conservation objectives of the site in question."

Also note that Electricite de France (EDF) has embarked on a strategic initiative on "water partitioning" – France's term for long range planning among competing users of fresh water resources. EDF uses computer models of future environmental impacts of climate change on diminished fresh water resources as the quantitative basis for this long-term planning effort.

In the U.S., all once-through-cooled nuclear plants withdrawing cooling water from oceans, estuaries, or tidal waters were granted construction permits in the 1964-1977 timeframe. Since then, no nuclear plant has been sited on such waters with the exception of Hope Creek. Hope Creek (construction permit in 1974; commercial operation in 1986) uses a cooling tower. All ESP and COL applications filed with NRC over the last decade (6 ESP sites and 18 COLA

sites) will use cooling towers, and all but two will use fresh water for cooling. The two exceptions are: PSEG's Salem/Hope Creek site (ESP on a tidal river), and Calvert Cliffs-3 (COLA on an estuary). Turkey Point 6/7 is on an ocean, but will use Dade County municipal waste treatment plant effluent [exempt from 316(b)] and cooling towers for cooling, similar to Palo Verde's arrangement with the City of Phoenix.

3.3 Application of Once-through Cooling versus Closed-cycle Cooling for New U.S. Facilities

3.3.1 Projected Growth in Nuclear Energy in the U.S.; Implications to Cooling Water

Expansion in the nuclear industry is occurring in three dimensions, all of which impact water use. New plants will add demand for more cooling water. Power uprates of existing reactors require incrementally more water, which in some cases translates to a modification to a plant's water permit and/or capacity of its cooling system. License renewal of existing facilities means that arrangements for water use need to be extended further into the future, potentially in the face of competing demands for that water.

The nuclear power industry continues to make progress toward the construction of new nuclear power plants in the U.S. To date, companies have submitted 16 license applications to the NRC for 25 new reactors. Twelve of these applications, representing 20 new reactors, are currently under active review. Of these, approximately 80% are on existing sites and 20% are on new sites. Combined operating licenses have been issued very recently by NRC for Southern Company's Vogtle Units 3 and 4, and SCANA's Summer Units 2 and 3, all using the recently approved Westinghouse AP1000 reactor design. The nuclear industry expects 4-8 new reactors in commercial operation by 2020.

Since 2000, the NRC has authorized 92 power uprates, yielding a cumulative capacity increase of 4,227 MWe. The NRC is currently reviewing 18 applications for uprates, totaling about 1,453 MWe of capacity. Over the next five years, the NRC anticipates that companies will apply for power uprates that could represent an additional 1,199 MWe of new capacity. The cumulative effect of these additions will average out to almost 70 MWe per reactor, or about a 7% increase on average in output for each unit. This in turn is roughly equivalent to a 7% increase in water usage (or somewhat less, if some plants have the flexibility to adjust cooling water discharge temperatures slightly upward).

Starting in 2000, the NRC began approving 20-year renewals of nuclear power plants' 40-year licenses, allowing those plants to operate for a total of 60 years. Since then, NRC has approved license renewals for 71 nuclear reactors, and has under active review requests for another 15 applications for renewal. Owners have formally announced intent to file application for renewal for an additional 17 reactors, leaving only one U.S. reactor that has not yet announced its intent to file (the newest one). Further, industry and DOE have initiated efforts to define the necessary R&D to support a further life extension beyond 60 years for U.S.

reactors (e.g., to 80 years or more). DOE and industry are working closely with NRC to ensure these efforts meet NRC requirements. If successful, these efforts would result in plant lives of at least 40-50 years beyond the average age of today's plants.

All of these opportunities for growth – new plants, power uprates for existing plants, and life extensions of existing plants – have implications to cooling water issues. Although utilities can reasonably predict regional power demands and associated cooling water needs a decade or more into the future, it is much more difficult for any nuclear plant owner to predict today what the competing demands for water will be at a specific site 60 to 80 years into the future. The only certainty is that water use demands are destined to grow in the future, not diminish.

Another nuclear power plant deployment option being considered by industry and DOE are Small Modular Reactor (SMR) concepts, currently being developed for licensing in this decade. Small-scale reactors can complement large nuclear plant projects by expanding potential markets in the U.S. and abroad for low-carbon energy production. Their small size (less than 300 megawatts), make them well-suited to replace older fossil generating capacity, taking advantage of existing transmission and cooling water infrastructure.

3.3.2 Options for Cooling Water Strategies for New Reactors on Existing Sites in the U.S.

Expansion of nuclear energy in the U.S. will rely heavily on existing nuclear sites. The following provides some rough estimates of the potential for building new reactors on existing sites:

- There are a number of existing sites with currently operating reactors that were originally planned and laid out in the 1960s or 1970s for more reactor units than were ultimately built. Situations where an order was placed but then cancelled are indicative of situations where new construction is possible today on a proven site issues of land availability, adequacy of water and transmission were previously resolved, and may remain within acceptable parameters today. There are 27 previously planned reactors on 19 sites in this situation. Nine reactors are now actively proceeding in the new plant licensing process (COL, ESP, or Part 50) on these sites, with two more reactors in suspended COLA review status.
- There are a number of existing nuclear sites with adequate space for new units, even though no formal plans or orders or construction permits were ever executed for additional units on these sites. In fact, seven of these sites have been selected for new plant construction in this decade, with 11 reactors proceeding through the new plant licensing process in this situation. These 11 reactors are in addition to the ones identified in the previous bullet.
- In addition to above, there are roughly 10 to 15 existing sites with currently operating reactors that neither have a history of prior plant orders nor any current plans to initiate new plant licensing, but that in theory should have

sufficient space, infrastructure, and regional power demand to support additional reactors.

In summary, about 40 of the 65 existing nuclear plant sites are either currently pursuing new plant licensing for that site, or have previously evaluated additional units for that site, or could, in theory, consider additional units for that site. This finding, in combination with the important statistic noted earlier that 80% of all active new plant licensing applications are for reactors on existing sites, clearly demonstrates the importance of existing nuclear plant sites to the expansion of nuclear energy in the U.S. This conclusion is not surprising. Existing sites typically have significant advantages over greenfield sites: established infrastructure including transmission access, exhaustive regulatory review of site characteristics important to reactor safety and environmental protection (e.g., seismicity and water resource characterization, respectively), state and local understanding of nuclear issues and associated licensing, permitting, and emergency planning processes. Consequently, these trends suggest that roughly 60% to 80% of new nuclear capacity would be constructed on existing sites.

However, it is important to recognize the challenges associated with siting new reactors on existing nuclear sites, relative to cooling water issues. This is especially true if cooling towers are mandated for retrofitting on current plants or are mandated for new plants on existing sites. These questions are the subject of the proposed rule discussed in the previous chapter.

In the proposed rule, EPA discusses the impacts of its requirements for new units on existing sites. For purposes of analysis, EPA established a value of 30% as the portion of new capacity that would be constructed at existing facilities based exclusively on fossil trends:

"In the Phase I Rule analysis, EPA determined that 76% of new coal and 88% of new combined cycle capacity would be constructed at new "greenfield" facilities and would be subject to Phase I requirements while the remainder (24% of coal and 12% of combined cycle) would occur at existing facilities and be subject to existing facility regulations. EPA has selected a conservative value of 30% reflecting both coal and combined cycle to serve as an estimate for the portion of new capacity that would be constructed at existing facilities. At existing nuclear facilities, only new capacity associated [with] the construction of new generating units would be subject to the new unit requirements. Considering their size and heat discharge as well as recent trends in industry, it is assumed that any new nuclear units will utilize closed-cycle cooling and so the capacity for these nuclear facilities is not included in the costs of requirements for new units."

. . .

⁹ Federal Register, Vol. 76, No. 76, April 20, 2011, pg. 22216.

Section 4: Comparison of Closed-Cycle Cooling Retrofits versus Once-Through Cooling

This chapter discusses a number of tradeoffs associated with once-through versus closed-cycle cooling. These include the environmental impacts associated with these technologies, cost and supporting infrastructure issues. One potentially significant environmental impact is evaporative water loss in fresh waterbodies; this topic is discussed separately in Chapter 5.

4.1 Once-through Cooling

Initially, once-through cooling was the standard for thermoelectric power plants. However, concerns developed over the effects of thermal discharges and later over cooling water intake structure (CWIS) effects. Statutory requirements were included in the Clean Water Act that resulted in a general shift to use of closed-cycle cooling systems for new power plants. This was especially the case where there was interest in siting larger generating facilities on smaller waterbodies. In 2001 EPA promulgated 316(b) regulations for new generating stations to address CWIS impacts. Those regulations designated closed-cycle cooling as BTA for new generating stations, but set a performance standard that would allow once-through cooling if a proposed facility demonstrated it could achieve a level of fish protection within 10% of the 90% level of protection that could be achieved with closed-cycle cooling.

There are a number of advantages associated with the use of once-through cooled plants that include:

- They generally achieve more efficient condenser cooling as a result of supplying the condenser with colder water than can be achieved with closedcycle cooling.
- They are significantly less expensive than closed-cycle cooling due to the avoided one-time capital cost of the cooling tower, avoided energy requirements of the cooling tower during operations, periodic maintenance of the cooling tower, and the reduced heat rate during operations.
- They avoid a number of potentially significant adverse environmental impacts discussed in Section 4.2.3 of this chapter.

• They consume much less water, as discussed in Chapter 5.

The two major advantages of closed-cycle cooling are the significant reduction in the thermal discharge, and reduced fish and shell fish mortality associated with the CWIS (i.e., impingement and entrainment mortality). As discussed later, the impingement and entrainment impact losses may be measurable in the immediate vicinity of the plant, but rarely are impacts measurable in the larger source waterbody.

EPA's 316(b) new facility rule allows use of once-through cooling under its "Track 2" as long as a level of fish protection can be achieved that is within 90% of that which can be achieved with closed-cycle cooling. The EPA Proposed 316(b) Rule for existing facilities does not designate closed-cycle cooling as BTA for impingement. For entrainment, the BTA decision is made on a case-by-case basis by the permitting authority as to whether or not closed-cycle cooling is BTA. Note that Options 2 and 3 do designate closed-cycle cooling as BTA.

4.2 Closed-cycle Cooling

As discussed in Chapter 3, closed-cycle cooling is currently used on 42 of the 104 nuclear units in the U.S. Of these, 34 use wet cooling towers (13 mechanical-draft towers; 20 natural-draft towers, and one unit that uses both) and eight use cooling ponds or cooling lakes that are treated as closed-cycle systems for purposes of 316(b). Plants on cooling ponds that don't qualify as exempt from 316(b) are considered once-through cooled plants. The several system types were described and discussed in Section 2.3.

4.2.1 Closed-cycle Cooling for New Facilities

As noted earlier, closed-cycle systems have a higher capital cost, and impose larger unit output reductions than would a once-through cooling system on an identical unit. EPRI has recently completed a study on cost/performance comparisons among alternative closed-cycle cooling systems. The study covered the three major closed-cycle cooling categories of recirculating wet cooling, dry cooling and hybrid cooling as applied to coal-fired steam plants, gas-fired combined-cycle plants and nuclear plants. The results of that study are discussed in Section 4.3.

4.2.1.1 Different Cooling Systems for New Facilities

Recirculating wet cooling: Wet cooling systems, comprised of a shell-and-tube surface steam condenser and a wet cooling tower, are described in Sections 2.3.1 and 2.3.2. Nearly all the cooling towers installed in recent years have been mechanical-draft towers (Section 2.3.1). Natural-draft towers (Section 2.3.2) were popular 20 to 40 years ago particularly for large, base-loaded plants including many nuclear plants. None had been built in the U.S for approximately 20 years until a recent installation at a fossil plant retrofit in southeastern Massachusetts. As discussed in Chapter 3, about 1/3 of the new nuclear plants under review by NRC for construction in the U.S. plan use of natural draft

towers. Recirculating wet cooling systems are likely to continue to be the commonly chosen system for both fossil and nuclear plants, primarily in response to §316 requirements. Some special circumstances may dictate the use of water-conserving systems at fossil sites, even in water-rich areas. Nuclear plants will generally be sited where adequate water resources are available.

Recirculating wet cooling systems are characterized by cold water temperatures approaching the wet bulb temperature of the atmosphere, water consumption rates in the range of 10 to 15 gpm/MW (including typical blowdown rates; or 8 to 12 gpm/MW, if estimated exclusive of blowdown), and moderate costs in the range of \$6,000 to \$10,000/MW.

Dry cooling: All the dry cooling systems installed in the U.S. are "direct" dry cooling of fossil plants in which steam from the turbine exhaust is ducted directly to an air-cooled condenser. These systems are described in Section 2.3.3. While natural-draft designs of air-cooled condensers are possible, none have been installed in the U.S., and relatively few have been used elsewhere in the world.

The number of dry cooling systems has increased substantially in the U.S. for fossil plant applications since the late 1970's as indicated in Figure 4-1 but the total plant capacity using dry cooling is still a small fraction of the utility industry capacity on closed-cycle cooling. The continued use of dry cooling on some new fossil plants is likely, particularly in the high population growth areas of the Southwest. As discussed in Chapter 2, dry cooling is not currently considered a practical option for nuclear plants.

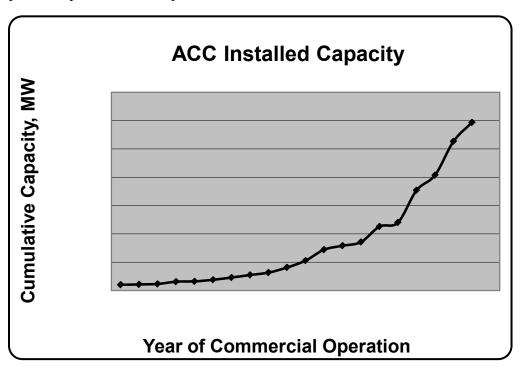


Figure 4-1
Dry cooling installations in the United States by year (Ref. 6)

Dry cooling systems are characterized by essentially zero water use, elevated turbine exhaust pressures on hot days, higher operating power requirements than the recirculating wet systems and higher capital costs, ranging from 3 to 5 times that of wet cooling.

Hybrid wet/dry cooling: Hybrid cooling systems consist of wet and dry elements which can be used separately or in conjunction with one another as conditions dictate. The typical wet/dry parallel configurations were described in Section 2.3.4. Only three such systems have been installed on new plants in the U.S. and all three have been of that design. Two of the plants are relatively small gas-fired, combined-cycle plants; the third, a large coal-fired steam plant. No hybrid systems have been installed to date on a nuclear plant, although such a system has been reviewed as an option for most new nuclear plants, and has been included in plans for one plant (see Chapter 2 for details on North Anna-3). Hybrid cooling systems have been designed to conserve as much as 20-80% of the water consumed in wet cooling systems. Use of these systems has been adopted where stakeholder involvement or permitting requirements have required a reduction in the amount of water consumed by the facility.

4.2.1.2 Cost/Performance Comparisons for Closed-cycle Cooling Systems for New Plants

A recent EPRI report [Ref. 7] provides a detailed study comparing the costs, water requirements, and the annual energy production of fossil and nuclear plants equipped with wet, dry and hybrid cooling systems. The results for the three plant types are shown in tabular form in Table 4-1. The same results are shown in graphical form for nuclear plants in Figure 4-2.

Table 4-1 Cost performance comparisons for alternative cooling systems at three plant types at five representative sites (Ref. 7)

COAL FIRED STEAM PLANT															
	Yuma		Jacksonville		Bismark		Burlington			St. Louis					
Cooling System	\$	MWh	kgal												
	x10^ ⁶														
Wet	3.56	4.40	2.18	3.59	4.40	1.91	3.39	4.40	1.67	3.41	4.40	1.72	3.56	4.40	1.79
Dry direct	18.10	4.10	0.00	15.00	4.19	0.00	11.60	4.21	0.00	11.70	4.20	0.00	13.60	4.20	0.00
Dry indirect	31.00	4.10	0.00	25.00	4.17	0.00	18.30	4.27	0.00	18.50	4.23	0.00	21.20	4.20	0.00
Hybrid	13.50	4.27	1.32	12.40	4.29	0.87	10.30	4.32	0.46	9.90	4.32	0.47	11.30	4.30	0.72
NUCLEAR STEAM PLANT															
	Yuma		Jacksonville		Bismark		В	urlingt	on	St. Louis					
Cooling System	\$	MWh	kgal												
System	x10^6	x10^6	x10^ ⁶	x10^6	x10^6	x10^ ⁶	x10^6	x10^6	x10^6	x10^ ⁶	x10^6	x10^6	x10^ ⁶	x10^ ⁶	x10^6
Wet	4.66	5.21	3.49	4.7	5.19	3.05	4.39	5.23	2.64	4.42	5.23	2.74	4.62	5.22	2.86
Dry indirect	39.70	4.86	0.00	28.50	5.03	0.00	24.60	5.06	0.00	24.60	5.06	0.00	28.80	5.00	0.00
Hybrid	30.60	5.03	2.42	30.70	5.03	1.68	26.00	5.08	0.96	26.50	5.08	0.98	28.00	5.06	1.46
			-			-				-					
					GAS-	FIRED,	сомві	NED-CY	CLE						
		Yuma		Jacksonville		Bismark		Burlington		St. Louis		;			
Cooling System	\$	MWh	kgal												
- /	x10^6	x10^6	x10^ ⁶	x10^ ⁶	x10^6	x10^ ⁶	x10^6	x10^6	x10^6	x10^ ⁶	x10^6	x10^ ⁶	x10^ ⁶	x10^ ⁶	x10^ ⁶
Wet	1.70	4.46	1.17	1.70	4.56	0.98	1.64	4.56	0.82	1.63	4.56	0.83	1.67	4.56	0.92
Dry direct	8.77	4.55	0.00	7.10	4.55	0.00	6.60	4.55	0.00	6.40	4.55	0.00	7.90	4.55	0.00
Hybrid	6.90	4.64	0.85	6.30	4.56	0.54	5.00	4.56	0.23	5.00	4.56	0.22	5.70	4.56	0.36

Nuclear Plant Cooling System Comparisons (Annualized costs; annual ouput; annual water consumption)

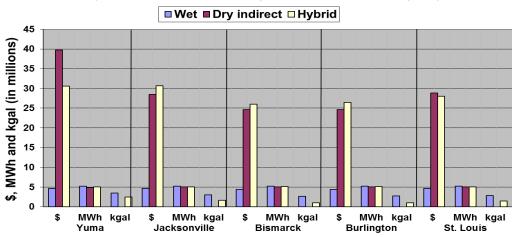


Figure 4-2 Cost performance comparisons for nuclear plants at five representative sites of differing meteorology (Ref. 7)

The cost comparisons above focus on differences among wet, dry, and hybrid closed-cycle cooling technologies. No recent quantitative studies that compare the relative costs of wet closed-cycle cooling to once-through cooling are available. As discussed in the next section, "the cost and related penalties of closed-cycle cooling are both much higher for retrofits than for new plants." Stated differently, the cost differential for new plants between once-through cooling and closed-cycle cooling is much smaller than for the retrofit case. Thus, the requirements of the CWA Phase 1 rule discussed in Chapter 2 that strongly favor closed-cycle cooling for new plants, does not create a huge issue for new plants from a cost perspective (in contrast to the retrofit scenario), all other factors being equal. The practical implication of this cost contrast is that the "Track 2" option available in the Phase I Rule has been rarely used.

This does not mean that the cost differences between once-through cooling and closed-cycle cooling for new plants are zero. Clearly, the cost penalties associated with closed-cycle energy requirements (e.g., fans) combined with the heat rate penalty, apply to new plants, resulting in a net reduction in plant efficiency of 2-4%, with its associated cost penalty.

Capital costs for closed-cycle cooling would also be somewhat higher than for once-through cooling, although the differences are relatively small compared to total plant cost. Higher capital costs for closed-cycle cooling are associated with the cost of cooling towers and a larger condenser. Higher costs for once-through cooling are associated with larger circulating water pumps and larger CWISs.

4.3 Cooling System Retrofits for Existing Facilities

4.3.1 Costs of Retrofits

It is widely understood [EPA Ref. 8; EPRI Refs. 9-14, DOE Ref. 15] that the cost and related penalties of closed-cycle cooling are much higher for retrofits than for new plants. EPRI recently published a detailed study [Ref. 9] of retrofit costs assuming a common approach to retrofit illustrated schematically in Figure 4-3.

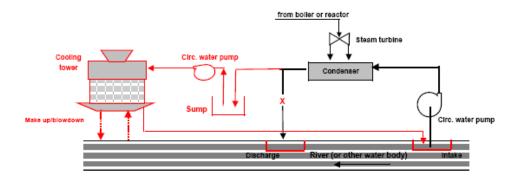


Figure 4-3
Schematic of closed-cycle cooling retrofit arrangement

The primary assumptions in the EPRI study were:

- 1. The original condenser and circulating cooling water flow rate remain unchanged
- 2. The cooling tower will be a counterflow, mechanical-draft tower

EPRI identified ten cost elements that would make up the total cost to retrofit should closed-cycle cooling be designated BTA for the industry. These cost elements were:

- 1. Cooling tower capital cost (hardware and construction cost)
- 2. Cost of capital to finance the project
- 3. Revenue loss for extended outages to tie in the cooling tower system
- 4. Energy penalty (lost revenue due to energy requirements for cooling tower fans and pumps)
- 5. Heat rate penalty (lost revenue due to reduced condenser cooling efficiency with a cooling tower compared to once-through cooling)
- 6. Operating and maintenance cost (labor and materials to operate and maintain the closed-cycle system)
- 7. Permitting costs
- 8. Cost of replacement power generation (replacement power to offset loss of generation due to premature facility retirement in response to economic or permitting issues)
- 9. Cost of electric system upgrades (upgrades to the electric system due to generation losses from the energy penalty, heat rate penalty, prematurely retired facilities) as a result of shifting voltage loads to the transmission system that may not be designed for the new loads
- 10. Environmental and social costs (e.g., monetized costs to avoid environmental effects of closed-cycle cooling such as noise, drift, habitat loss, increased consumptive water loss).

Cost elements 1-7 are facility specific costs that would reasonably be considered by each facility in making the economic decision on whether or not to retrofit. Cost elements 8 and 9 are costs that would be borne by the industry as a whole and cost element 10 represent social costs that would be borne by populations in proximity to the closed-cycle system. A summary of those costs for the 39 once-through cooled nuclear facilities is provided below.

Data from a number of independent sources, including actual retrofits and detailed engineering studies by utility engineering departments and established A&E firms gave a range of retrofit capital. These costs had the following features.

1. For plants of comparable capacity, the costs for nuclear units exceeded those for fossil units

- 2. At a given circulating water flow rate, there was typically a wide range of costs which were assumed to correspond to retrofits of varying degrees of difficulty determined by site-specific factors
- 3. For plants of similar difficulty, the costs were generally scalable linearly with circulating water flow rate.

4.3.1.1 Capital Cost

EPRI completed a study to estimate the cost of retrofitting the existing once-through cooling generating units to inform the §316(b) Rulemaking [Ref. 9]. In that study estimates were made of the capital cost to retrofit both fossil and nuclear facilities. The study approach was to construct a model based on a relatively high degree of correlation between a number of site-specific closed-cycle cooling retrofit cost estimates and the volume of cooling water flow. Of the 39 nuclear facilities, 16 facilities (41%) had conducted site-specific retrofit cost estimates. Based on correlations, cost coefficients were established for both nuclear and fossil facilities to retrofit cooling towers.

The cost coefficients for the four degrees of difficulty for fossil plant retrofits are:

Easy: \$181/gpm Average: \$275/gpm Difficult: \$405/gpm More Difficult: \$570/gpm

The cost coefficients for the two degrees of difficulty for nuclear plant retrofits are:

Less difficult: \$274/gpm More difficult: \$644/gpm

The results showed that in general nuclear facilities were significantly more difficult to retrofit than fossil facilities. The EPRI study identified eleven factors that could result in a higher or lower normalized retrofit cost (\$/gpm) for any specific facility. These factors included:

- 1. The availability of a suitable on-site location for a tower(s)
- 2. The separation distance between the existing turbine/condenser location and the selected location for the new cooling tower(s)
- 3. Site geological conditions which may result in unusually high site preparation or system installation costs
- 4. Existing underground infrastructure which may present significant interferences to the installation of circulating water lines
- 5. The need to reinforce existing condenser and water tunnels
- 6. The need for plume abatement
- 7. The presence of on- or off-site drift deposition constraints

- 8. The need for noise reduction measures
- 9. The need to bring in alternate sources of make-up water
- 10. Any related modifications to balance of plant equipment, particularly the auxiliary cooling systems, that may be necessitated by the retrofit
- 11. Re-optimization of the cooling water system.

Based on these factors and information provided by facilities, EPRI conducted a Best Professional Judgment (BPJ) evaluation of 125 facilities including 10 nuclear facilities to estimate the capital cost to retrofit these facilities. Additional estimates were made of other costs related to retrofits including additional operating power, the cost of reduced unit efficiency and the cost of downtime during the retrofit process.

The results of that study are documented in detail in [Ref. 7]. The national retrofit costs, aggregated separately for fossil and nuclear are presented in tabular form in Table 4-2 below.

The total national capital cost of retrofitting all eligible facilities exceeds \$62 billion. The annual costs of additional operating power and reduced plant output due to cooling system limitations as well as one-time capital costs and revenue losses during the downtime required to accomplish the retrofits exceeds \$95 billion on a net present value basis. Nuclear plants account for 19% of the capacity of the family of Phase II facilities, but over 30% of the national capital costs of retrofit (i.e., \$32 billion).

Table 4-2 Summary of national retrofit costs (from [Ref. 7], Figure 9.1)

				Costs					
Plant Type	Source Water	Capacity	WaterFlow	Capital	Operating Power	Heat Rate Penalty	Downtime	Annualized Cost	Net Present Value
		MW	GPM	\$ millions	\$ millions	\$ millions	\$ millions	\$ millions	\$ millions
Nuclear	Great Lakes	6,000	3,840,000	\$1,760	\$13	\$16	\$740	\$200	\$2,860
	Lakes/Reservoirs	20,000	13,990,000	\$6,420	\$46	\$60	\$2,700	\$740	\$10,430
	O/E/TR	22,000	17,615,000	\$8,090	\$58	\$75	\$3,400	\$940	\$13,140
	Rivers	12,000	7,344,000	\$3,370	\$24	\$31	\$1,420	\$390	\$5,480
	Total Nuclear	60,000	42,789,000	\$19,640	\$141	\$182	\$8,270	\$2,280	\$31,920
	Great Lakes	27,000	14,242,000	\$4,330	\$44	\$54	\$920	\$480	\$6,460
	Lakes/Reservoirs	61,000	32,831,000	\$9,980	\$100	\$124	\$2,120	\$1,110	\$14,890
Fossil	O ceans/Estuaries/ Tidal Rivers	70,000	41,923,000	\$12,750	\$128	\$158	\$2,710	\$1,410	\$19,010
	Rivers	94,000	50,511,000	\$15,360	\$155	\$191	\$3,260	\$1,700	\$22,910
	Total Fossil	252,000	139,507,000	\$42,420	\$427	\$527	\$9,010	\$4,700	\$63,270
All plants	Total Phase II	312,000	182,296,000	\$62,060	\$568	\$709	\$17,280	\$6,970	\$95,190

Additional observations are:

• In general, retrofitting existing once-through cooled plants with closed-cycle cooling using cooling towers is much more difficult and costly than installing closed-cycle cooling at a new, greenfield site. This can be due to a variety of factors including limited space availability, underground interferences to the installation of circulating water piping, the need to relocate existing

- equipment and structures and the need to modify and upgrade existing circulating water intake/discharge structures and tunnels.
- There is a wide range for the cost of a retrofit depending on site-specific factors. Independent data sources indicated capital retrofit costs for fossil plants ranging from \$181/gpm to \$570/gpm, a factor of 3.2; for nuclear plants the range was from \$274/gpm to \$644/gpm, a factor of 2.6.
- The combination of the additional operating power requirements and the reduced plant efficiency are estimated to effectively reduce the available capacity of the family of Phase II plants by just over 3% or almost 10,000 MW.
- Additional capacity will be lost during the years in which the retrofit projects are underway due to extended outages at some plants where extensive modifications to the existing equipment are required. In aggregate this could result in the need to replace about 500,000 GWh from other sources or over 10% of the national power system's output from fossil and nuclear steam plants.
- Some facilities will be unable to retrofit primarily due to severe space constraints.

Attachment E, EPRI National Cost Estimate for Retrofit of U.S. Power Plants with Closed-Cycle Cooling: Technical Brief — Clean Water Act Fish Protection Issues, dated January 2011 provides a brief summary of EPRI's closed-cycle retrofitting report [Ref.9].

4.3.1.2 Extended Outages

A potentially significant cost associated with retrofits is the lost revenue from extended outages that may be required to connect the closed-cycle cooling tower to the condenser. For many fossil facilities this will not be an issue as many units serve only as peaking or cycling units to meet peak energy demand and do not operate for much of the year. However, nuclear units are all baseloaded with capacity utilization ranging around 90% or more. One nuclear facility, Diablo Canyon, based on a detailed study [Ref. 16] determined that a 17 month dualunit outage would be required as a result of site-specific difficulties, with an estimated \$1.8 billion cost for the lost revenue. The capital cost for the retrofit was estimated at \$2.7 billion in 2008 dollars, for a total capital plus power replacement cost of \$4.5 billion. Also, because the nuclear facilities are baseloaded with most having a relatively long remaining life, most would likely optimize the condensers for closed-cycle cooling to reduce the energy penalty. EPRI estimated that an average outage duration of 6 months would be required to retrofit nuclear facilities as a result of site-specific difficulties and/or condenser optimization. This would result in an estimated lost revenue cost of \$8.3 billion for the 39 nuclear generating stations.

4.3.1.3 Plant Efficiency

Retrofitting from once-through cooling to closed-cycle cooling results in a net reduction in generating efficiency. This is due to the need for some of the generated output to operate the fans in the case of mechanical draft cooling towers and the large pumps needed to pump cooling water to above the cooling tower fill, and the loss of generating efficiency experienced at most units due to the increased heat rate (i.e., the cooling tower cannot cool the water to as low a temperature as supplied from the source waterbody). Each of these factors is discussed.

4.3.1.3.1 Retrofit Energy Requirements

EPRI's Closed-cycle Cooling Research Program estimated the additional operating costs for cooling tower fans and pumps required for mechanical draft closed-cycle cooling systems. The gross annual O&M cost estimate was based on the assumption that the sum of the additional required operating power for the additional pumping head and the cooling tower fans ranged from 0.9 to 1.7% of plant output. For fossil plants, the mid-range value of 1.3% or 13 kW/MW was used. However, for nuclear facilities with an average normalized circulating water flow approximately 30% higher than fossil plants, the high end of the range, 17 kW/MW, was used. The higher water use for nuclear facilities compared to fossil facilities is because none of the waste heat generated in the reactor system is emitted up a stack¹⁰ so that all of that heat is transferred to the cooling water. In addition, the steam temperature and pressure of nuclear units is lower than a typical fossil unit, so the heat-rate for nuclear plants is inherently lower. Hence, the thermal cycle in a reactor used to produce electricity is somewhat less efficient for nuclear than fossil facilities, and the additional waste heat must be removed by the cooling system.

As discussed in the previous section, most baseloaded nuclear facilities would likely re-optimize the condensers to reduce the energy requirements. Doing so would allow the circulating water flow and the tower size to essentially be halved. Re-optimization involves changing the condenser from the one-pass design typically used in once-through cooling (high flows, single pass, low 10-20°F temperature rise) to a two-pass design typically used for closed-cycle cooling (lower flows, two pass, high 35-45°F temperature rise). With the higher temperature rise achieved by a two pass condenser, the cooling tower can be optimized (smaller tower) because of the higher driving force for heat rejection to ambient air. The two pass condenser design also minimizes the condensate return temperature, as the coldest water is passed through the bottom pass of the condenser. In a new system, this would also allow for reductions in circulating water pipe sizes. This design usually requires that the condenser water boxes be partitioned, and either the inlet or outlet circulating lines be moved to the opposite side of the turbine.

¹⁰ Unlike fossil plants, nuclear plants don't have a "stack" for dispersion of combustion product air emissions.

These structures are often located below-grade, which further increases the complexity and cost of such a retrofit. It is much easier to design and build the balance of plant (BOP) to the plant's design parameters and intended cooling mode than to change it later.

One benefit of re-optimization would be slightly lower capital cost for the cooling tower, but this would not offset the increased costs for the condenser and circulating water line modifications. The biggest benefit would be the increased efficiency achieved by the optimized system for the remaining life of the plant. This kind of retrofit would be most cost-effective for nuclear plants, since they would suffer a larger penalty than fossil plants with an unoptimized system. The large capital investment in re-optimization would likely be amortized over a longer time period, with a base loaded plant running at 90% or higher capacity factor.

Assuming that all nuclear plants would re-optimize, 8.5 kW/MW (one-half of the 17 kW/MW discussed in the previous paragraph) was assumed as the average operating cost for the nuclear facilities. See Ref. 9 for details on optimization assumptions.

Based upon the assumptions discussed, the estimated national cost associated with the energy penalty was \$141 million annually for the 60,000 MWs of nuclear generation and \$427 million for the 252,392 MWs of fossil generation. Thus, while nuclear generation makes up approximately 19% of the total once-through cooled generation, assuming all once-through cooled generation were required to retrofit, the nuclear facilities would bear 25% of the energy penalty cost.

4.3.1.3.2 Heat Rate Penalty

Because lower condensing water temperatures can almost always be achieved with once-through cooling than with a closed-cycle cooling system, there is a heat rate penalty associated with closed-cycle cooling. This penalty results in a net decrease in the generating capacity for units that use closed-cycle cooling. The amount of this penalty varies during the course of the year but is greatest during hot weather summer temperatures, which coincide with the period of peak seasonal energy demand and energy prices for most regions of the U.S.

A calculation similar to that for the energy requirements can be made of the cost of the annual energy penalty resulting from the increased turbine backpressure and reduced turbine efficiency. EPRI [Ref. 9] made these calculations for "hot day" and "annual average" conditions for example sites in seven geographical regions with differing climates and source waters. They show a wide range varying from -0.9 to 1.15 inches Hga on hot days with an average of about 0.6 inches Hga and from 0.55 to 1.41 inches Hga with an average of about 0.9 inches Hga at annual average conditions. EPRI's study found the differences stem from differences in the source water temperature for once-through cooling and the wet bulb temperature plus the tower approach for closed-cycle cooling. Based on this information EPRI estimated the aggregated national cost of the

energy/capacity penalties associated with the heat rate penalty. The average backpressure increase across the seven regions was used for the hot day and annual average conditions (see Ref. 9, pg. 18). The output reduction per unit increase in turbine exhaust pressure, expressed as "% reduction per inches Hga," was assumed to be 1%/inch Hga at annual average conditions and 2%/inch Hga at hot day conditions. "Hot day" conditions were assumed to pertain for 10% of the year (876 hours) and annual average conditions for the remainder of the year (7,884 hours). The reduced output for baseloaded nuclear facilities (which are unable to compensate, as some fossil units can, for the energy loss by over firing), was valued at \$35/MWh. For fossil facilities that may be able to over fire, the same assumptions were made as in the previous section. The result was an estimated cost for the 60,000 MWs of once-through cooled nuclear generation of \$182 million/yr. and \$527 million/yr. for the 252,392 MWs of fossil generation. The nuclear capacity which comprises 19% of the once-through cooled capacity incurred approximately 26% of the national annual heat rate penalty cost estimate.

It should be noted that in some cases, such as in the southeast on small rivers or in the south central area on small ponds or lakes, the source water temperature in the summer can exceed the temperature of cold water available from a cooling tower. Therefore, there can be a net increase in hot day efficiency and output with closed cycle cooling. These considerations, while rare, were factored into the establishment of the average penalty.

4.3.1.3 Other Facility Specific Costs

EPRI identified three additional costs that would be incurred but were not estimated as part of the study. These included the cost of labor and chemicals to control biofouling and scaling of the cooling towers, permitting costs and the cost to finance the capital construction. In general these costs would also be expected to be higher on a per MW basis for nuclear than fossil facilities. The labor and chemical cost would be greater due to use of approximately 30% more water on average needed for nuclear facilities than fossil facilities. The permitting costs would be expected to be higher due to extra layers of regulatory oversight for nuclear facilities, and the cost of capital would be higher due to the higher estimated average cost of approximately \$457/gpm to cool average nuclear facilities (33.5% higher than the average cost of \$304/gpm to cool fossil facilities). While none of these costs is considered trivial, these costs are not considered to be of the magnitude estimated for capital cost, lost revenue for extended outages and cost of reduced generation output as a result of cooling system energy requirements and reduced heat rate efficiency.

4.3.1.4 Other Cost Related Considerations

Two important considerations here are: 1) can the nuclear facilities bear the cost of retrofits, and 2) potential impacts to the electric system. Each is discussed briefly.

In the EPRI study of potential financial impacts of a closed-cycle cooling retrofit requirement [Ref. 10] it was estimated that approximately 26,000 MWs of fossil generation was at risk of premature retirement for economic reasons if required to retrofit. For many older units with low capacity utilization the economics would favor retiring the plant rather than retrofit with closed-cycle cooling, since they would become even less economical. All of the nuclear facilities are baseloaded and none was forecast to be prematurely retired. However, the owners of Oyster Creek (currently the oldest nuclear facility in operation in the U.S.), under pressure to retrofit cooling towers due to thermal and cooling water intake structure concerns, announced that the plant would be retired 10 years sooner than planned to avoid retrofitting with closed-cycle cooling.

EPRI's study of potential impacts of a closed-cycle cooling retrofit requirement to electric system reliability [Ref. 11] identified a potential risk in 3 of 5 NERC Regions studied as a result of the premature retirement of the 26,000 MWs of fossil generation. None of the nuclear units was expected to retire. The result of the premature fossil unit retirements in the three NERC Regions (ERCOT, New England ISO and New York ISO) was the potential need for electric system upgrades as a result of the risk of localized voltage exceedances and/or security violations. While EPRI modeling did not specifically consider the downtime associated with the baseloaded nuclear units (Section 4.2.2.1.2) or the loss of generation efficiency (Section 4.2.2.1.3), there is potential for those generation losses to impose additional electric system reliability risks.

4.4 Environmental Considerations

Closed-cycle cooling reduces localized fish and shellfish mortality associated with cooling water intake structure impingement and entrainment, in addition to reducing the thermal impacts of once-through cooling. However, there are a variety of potential environmental and social impacts associated with closed-cycle cooling, the significance of which varies on a site-specific basis. These potential impacts include effects on terrestrial resources, aquatic resources, public safety and security, degradation of quality of life and greenhouse gas emissions. EPRI's Closed-cycle Cooling Research Program included a study of those impacts (Ref. 12). Where possible those impacts were quantified and monetized. The purpose of this section is to provide a summary of those impacts relative to nuclear generation stations. There is a significant difference in considering potential environmental and social impacts for new facilities versus retrofits for existing facilities. That is, for new generating facilities, those impacts can be considered in context with the impacts of constructing the entire new generation project, which allows maximum flexibility to mitigate those impacts in the overall project design. In the case of closed-cycle cooling retrofits, due to the existing facility land use and available space, opportunities to mitigate the closed-cycle cooling impacts may be more limited. The quantified and monetized benefits associated with those reductions are the topic of Chapter 6.

4.4.1 Environmental and Social Impacts of Closed-Cycle Cooling

In general the environmental and social impacts of cooling towers installed at nuclear facilities have the same issues as those installed at fossil facilities and the potential impacts to the environment include:

- terrestrial wildlife due to noise and habitat loss
- terrestrial natural vegetation due to habitat loss and particulate deposition
- agricultural crops due to particulate deposition
- fish and aquatic life through consumptive water use and the removal of harmful debris such as plastic material that cause entanglement (an issue for arid regions).

These can include impacts to rare, threatened or otherwise protected species of wildlife or vegetation.

Cooling towers also have the potential to pose a risk to public safety as a result of increased icing and fogging along roadways and nearby airports.

Cooling towers can have social impacts as a result of noise and aesthetics. The significance of all of these impacts tends to be site-specific and is a function of the location of the cooling tower on the property and its proximity to:

- urban, suburban or residential populations
- agriculture land
- wetlands
- forests
- parks
- seashores
- sensitive habitat for protected species of fish and/or wildlife.

Another important factor relative to potential environmental and social impacts is the type of waterbody from which cooling water is withdrawn. Facilities withdrawing from tidal waters have increased levels of salt deposition compared to those using freshwater. The salt deposition may adversely affect surrounding vegetation or damage property. Thirteen existing nuclear facilities (one third of the total), withdraw cooling water from oceans, estuaries or tidal rivers.

The EPRI study on environmental and social impacts was based on a detailed analysis of 24 representative facilities. Six of the 24 facilities were nuclear facilities. Following are the areas where there is a significant difference in the potential impacts between fossil and nuclear facilities:

1. The Overall Level of Impact – As discussed in Chapter 3, virtually all nuclear facilities are baseloaded and have an average generation capacity that is larger than the average for fossil units. The result is that impacts in the form of

- noise, salt drift, fine particulates, water consumption and visible plumes are present almost continually, compared to many fossil units that operate less frequently. Additionally, the overall level of these impacts may be greater, since these facilities tend to be larger and require larger cooling towers.
- 2. Greenhouse Gas Emissions Installation of closed-cycle cooling would increase greenhouse gas emissions by lowering the thermal efficiency of fossil and nuclear plants and as a result of any fossil generation used to replace lost nuclear capacity.

A significant advantage of nuclear generation is that no greenhouse gases are emitted as part of the generation. However, if the baseloaded nuclear facilities were required to retrofit with closed-cycle cooling, EPRI has estimated that on average, an extended outage of six months or longer duration may be required. The result is that the replacement power during these outages would likely be generated from fossil fuel. EPRI's best estimate of the amount of greenhouse gas emissions is based on the assumption of an average six month outage; however, EPRI also estimated emissions assuming an eight month outage. These two estimates bracket EPA's estimate in the 316(b) Proposed Rule of a seven month extended outage duration. Assuming a 6-month outage, it is estimated that 163 million tons of CO₂ would be generated for all once-through nuclear units, with 74 million tons from facilities on lakes and reservoirs, 67 million tons from oceans, estuaries and tidal river facilities and 22 million tons from facilities located on the Great Lakes or small rivers. Assuming an 8-month outage, it is estimated that 212 million tons of CO₂ would be generated for all once-through nuclear units with 99 million tons from facilities on freshwater lakes, reservoirs or large rivers, 84 million tons from oceans, estuaries and tidal rivers, and 29 million tons from facilities located on Great Lakes or small rivers. The estimated willingness to pay (WTP) to avoid this impact, based on carbon markets using an average price of \$3.80 per ton of CO₂ in 2007\$, are \$13,000,000 and \$16,900,000 for 6- and 8-month outages, respectively. However, the \$3.80 price, while representative of carbon markets at the time of the study, does not represent the likely price in a world with a national carbon cap or international carbon agreement to which the U.S. is party.

Section 5: Water Consumption Rate Data for Once-Through Cooling versus Closed-Cycle Cooling

This chapter discusses the water availability issue and the potential for water use conflicts as consumptive use grows over time. It reviews the relative water consumption rates for the two primary modes of plant cooling, noting a recent National Laboratory conclusion that recirculating cooling technologies consume at least twice as much water as once-through cooling technologies. Actual consumption data are limited, so this conclusion carries uncertainty. Based on work by another National Laboratory, this chapter attempts to project the long term impacts of a significant expansion of closed-cycle cooling, with its higher consumption rates, on water use in the U.S. These results are regional-specific and often site-specific. Finally, this Chapter discusses the relationship between the 316(b) proposed rule and consumptive water use.

5.1 Overview of Issue

Population growth and societal demand for improved quality of life will require more clean water for drinking and sanitation, more water for irrigation of crops to feed more people, and expanding supplies of affordable and reliable energy to meet basic human needs and to enable substantial growth in industry and commerce. In contrast, the fresh water resources needed for the many aspects of sustainable development are limited and essentially unexpandable.

The consumptive use of water has major strategic implications to the U.S. and globally. Water shortages and water use conflicts are already major concerns in some parts of the U.S. Increased demand by multiple water users (e.g., agriculture, municipal water utilities, mining; and water consumption associated with alternative energy sources such as bio fuels and oil shale) are anticipated, and shortages are expected to become increasingly acute in coming decades.

Many organizations have concluded that water resources will be affected by many factors in the future, and this has major impacts on the energy/water nexus. Following are quotes from recent reports that reinforce the importance and urgency of water availability as an issue:

"We will run out of water long before we run out of fuel," and "... the seriousness of the water crisis will impinge on our lives much earlier than climate change." (World Economic Forum (WEF) website: http://www.weforum.org/en/index.htm.) [Ref. 17]

"However, as population has increased, demand for energy and water has grown. Competing demands for water supply are affecting the value and availability of the resource. Operation of some energy facilities has been curtailed due to water concerns, and siting and operation of new energy facilities must take into account the value of water resources. U.S. efforts to replace imported energy supplies with nonconventional domestic energy sources [e.g., biofuels, including ethanol and biodiesel; oil shale, oil sands, etc.] have the potential to further increase demand for water." ("Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water," DOE, Dec. 2006.) [Ref.18]

"Our experiences tell us that environmental stress, due to lack of water, may lead to conflict, and would be greater in poor nations." (Ban Kimoon, Secretary General of the United Nations, pledging action on water resources at the World Economic Forum held on 24 January 2008 [see Ref. 17]. He cited a recent report by International Alert identifying 46 countries, home to 2.7 billion people, where climate change and water-related crises create a high risk of violent conflict.)

"Water is emerging as a significant factor in economic development activities. Planning efforts must consider the availability and quality of water resources in a given locality or region to ensure that supplies are available to accommodate existing and future water consumers over the long term. Failure to do so can result in stunted growth, economic flight, inequitable development, and even open conflict." (Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements, NETL, Sept. 2011) [Ref. 19]

"Conflicts between energy production and water availability are on the rise as the overall pressure on scarce water resources intensifies. Rising energy costs and concerns about greenhouse gas emissions are forcing some water managers to seek ways optimize the energy efficiency of their water systems. Likewise, water scarcity is beginning to affect energy production, even in areas not traditionally associated with water-supply constraints. Water-energy conflicts are most acute during a drought, especially in the summer, when energy demands are high and water availability is particularly low." (Water for Energy: Future Water Needs for Electricity in the Intermountain West, Nov. 2011) [Ref. 20]

"Despite these concerns, water and energy policies are rarely integrated. Federal policies are being developed with little understanding or concern about the impacts on water resources. In particular, the federal government, through subsidies for corn production, has massively increased the production of ethanol, with little concern for the water supply and quality implications of this policy. ... A number of new trends, including rising electricity demands, the application of carbon capture and storage technologies, and the pursuit of increasingly energy-intensive water-supply options, suggest that the conflict between energy and water resources might intensify in coming years and pose a serious risk to the future availability and quality of our nation's water and energy resources. In combination, these concerns and new trends highlight the need to better integrate water and energy policy." ... [Ref. 19]

"Questions for Congress include who is the most appropriate entity to respond to energy's growing water demand and water vulnerability and how to respond. At present, little direct federal action is aimed at managing the energy sector's water demand; instead, the current division of responsibilities relies on energy interests and state and local governments to meet and manage energy's water demand and resolve energy-water conflicts. The role of federal policies in contributing to rising water demand is bringing into question the future federal role in this policy arena. Local or regional competition for water with existing users is often what makes energy's water demand significant; at the same time, the regional and local scales of water resources availability and management complicate many federal water-related actions."

(Energy's Water Demand: Trends, Vulnerabilities, and Management, Congressional Research Service, January 2011) [Ref. 21]

"Unfortunately, most nations also suffer from a fragmented approach to water management. In the United States, more than 20 different federal agencies have responsibility for various aspects of water policy, and with a few notable exceptions (the Netherlands and Israel) the situation is similar elsewhere. Under this fragmented approach, integrating water policies and management across several sectors is easier said than done. In many cases, government departments have policies or regulations that are at odds with each other, such as environmental regulations that severely restrict the re-use of domestic waste water. ("The Energy Challenge", Nature, March 2008, M Hightower) [Ref. 22]

Clearly, thermoelectric power plants – one of the key users of water – are expected to come under increasing pressure to reduce their consumption of water. Given that closed-cycle systems, in general, consume at least twice as much water as once-through systems, it is anticipated there might be increasing instances where state and regional water authorities in water constrained regions of the U.S. press for reducing water consumption by the electric power generation industry.

Increased water consumption rates associated with closed cycle cooling have the potential to result in increased water impacts in some regions of the U.S.

Although actual consumption data are currently limited, this chapter attempts to estimate, based on these limited data, the long term impacts of a significant expansion of closed-cycle cooling (including new plant trends) on the consumptive water use in the U.S.

5.2 Relative Water Consumption Rates for Once-Through vs. Closed-Cycle Cooling

5.2.1 NREL Study Conclusions

Even though virtually no water is consumed immediately by once-through cooling during the cooling process itself, water may evaporate later from the "thermal plume" that is created. This is because the warmer discharge water has an incrementally higher evaporation rate than the cooler source water. Historically, estimates of these incremental evaporation rates have been difficult to establish based on plant data, often leading to indirect estimates based on complex models that consider temperature, humidity, wind speed and other factors. Water consumption rates from closed-cycle cooling, on the other hand, can be calculated rather accurately from makeup and blowdown data.

A recent study of water consumption rates for once-through cooling vs. closed-cycle cooling has been prepared by the National Renewable Energy Laboratory (NREL): "A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies," March 2011. [Ref. 23]

One important conclusion of this study is that "recirculating cooling technologies consume at least twice as much water as once-through cooling technologies."

Although a very recently issued report, this study relies on decades of data and prior studies.

The report's methodology was summarized as follows: "Data sources include published academic literature, state and federal government agency reports, non-governmental organizations' reports, and industry submissions to government agencies for permitting procedures." ... NREL "... report[s] minimum, maximum, and median values for fuel technology and cooling system combinations in tables and additionally show 25th and 75th percentile data in figures." Median values for consumptive use of water by nuclear plants were: 672 gal/MWh for closed-cycle cooling, and 269 gal/MWh for once-through cooling.

The NREL study also notes that: "Federal datasets on water use in power plants have numerous gaps and methodological inconsistencies. Federal agencies are currently coordinating to improve these data. Water use factors discussed here are good proxies for use in modeling and policy analyses; at least until power plant level data improve." This coordination follows numerous recommendations in a recent GAO report [Ref. 24], and is being led by the USGS and the EIA.

Prior studies by EPRI and other national laboratories, going back over two decades, have consistently indicated that closed-cycle cooling consumes

significantly more water than does once-through cooling, typically approaching a factor of two. DOE's Report to Congress: "Energy Demands on Water Resources: A Report to Congress on the Interdependency of Energy and Water," [Ref. 18] relied on EPRI and national laboratory data. The DOE report listed nuclear plant water consumption factors at 400 gal/MWh for once-through cooling and 720 gal/MWh for cooling towers, based on EPRI analysis. These and other consumption data in the DOE report were based on data from EPRI, California Energy Commission, NREL, NRDC, and the Pacific Institute.

5.2.2 Empirical Derivation of Once-Through Cooling Water Consumption Rates

An attempt was made in the preparation of Ref. 4 to determine water consumption rates for once-through cooling on an empirical basis. The strategy for doing this was to find data for plants operating on cooling ponds, which in theory have the ability to determine water consumption rates empirically, using makeup, blowdown, and rainfall data, similar to how closed-cycle plants can develop these data. Since makeup to cooling ponds is not continuous (typically intermittent and/or seasonal), the methodology requires determining a full power water consumption rate and a zero-power water consumption rate, and subtracting the latter from the former to determine the amount of water consumption due to evaporation that results from warmer discharge temperatures. Obtaining zero power water consumption data is problematic, unless quality data were obtained during an extended outage at the site (or during pre-commercial pond operations, if monitored). Data points were obtained from two plants using the above approach that suggest that once-through cooling water consumption rates are in the range of 300 gal/MWh. This empirical approach supports the NREL conclusions above.

5.2.3 Recognition by EPA of Cooling Towers' High Water Consumption Rates

EPA's proposed 316(b) existing facility rule was issued in March 2011, acknowledging the issue of consumptive use of water.

"While wet cooling towers reduce withdrawals relative to once-through systems, they may increase the consumptive use of water since they tend to rely on evaporation (which is not returned to the waterbody) for heat dissipation. When once-through cooling is used and withdrawals are a significant portion of the waterbody, the return of heated water may contribute to greater evaporation from the waterbody. However, EPA does not have data on the relative magnitude of these effects. The relative loss of water through evaporation for closed-cycle and once-through systems is site specific, depending on the exact design of the systems."

¹¹ Federal Register, Vol. 76, No. 76, April 20, 2011, pg. 22199.

5.3 How Important is a Factor-of-Two Higher Water Consumption Rate for Closed-Cycle Cooling vs. Once-Through Cooling?

5.3.1 NETL Study Conclusions

The DOE National Energy Technology Laboratory (NETL) periodically publishes a report entitled, "Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements." This report was first issued in 2004 and is updated annually. The latest report is dated Sept. 2011 [Ref. 19]. It contains estimates for five scenarios, with data presented on both a national average and regional basis. The national and regional data on electricity demand and capacity forecasts come from the DOE's Energy Information Administration's (EIA's) Annual Energy Outlook (AEO). The regional assessment was done in prior years based on 13 North American Electric Reliability Corporation (NERC) regions, but the most recent update shifted to the 22 Electricity Market Module (EMM) regions that EIA implemented for their 2011 AEO. Data are presented for all thermoelectric power plants in the U.S. (including nuclear), as well as for various breakdowns in fossil technologies.

Nuclear-specific water needs are not broken out explicitly in the report, and EIA projections tend to be conservative with regard to both nuclear plant license renewal and new plant construction. Nevertheless, the NETL report is a good reference for understanding future water needs. NETL estimates future water requirements (both withdrawal and consumption needs) for five scenarios. These five scenarios apply to all electric generation: fossil, nuclear, and renewables.

NETL defines their five cases and approach to developing these cases as follows:

- "Case 1 Additions and requirements are proportional to current water source and type of cooling system.
- Case 2 All additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system.
- Case 3 90% of additions use freshwater and wet recirculating cooling, and 10% of additions use saline water and once-through cooling, while retirements are proportional to current water source and cooling system.
- Case 4 25% of additions use dry cooling and 75% of additions use freshwater and wet recirculating cooling. Retirements are proportional to current water source and cooling system.
- Case 5 Additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system. Five percent of existing freshwater once-through cooling capacity is retrofitted with wet recirculating cooling every five years starting in 2015."

"Future water withdrawal and consumption for the U.S. thermoelectric generation sector are estimated for five cases – one reflecting status quo conditions, two reflecting varying levels of regulations regarding

cooling water source, one incorporating dry cooling, and one reflecting regulatory pressures to convert existing once-through capacity to recirculating capacity."

"The five cases were selected to cover the range of possible design choices for new power plants including the source of water (fresh or saline) and type of cooling system (wet recirculating or dry). In addition, Case 5 assumes that 25% of existing power plants with a once-through cooling system are retrofit with a wet recirculating system. For all five cases, it is assumed that plant retirements occur proportional to current water source and cooling system type."

Since a primary goal of this chapter is to estimate the impacts of potential widespread expansion of closed-cycle cooling on the consumptive use of water in the U.S., it is necessary to estimate which of the above five cases represents the most likely future rate of conversion from once-through cooling to closed-cycle cooling in the U.S. It is important to note that the proposed EPA rule conducted extensive analysis of the cost impacts of such conversions under its three options, as discussed previously in Chapter 2. EPA also examined the impacts of its three options on other important considerations, including impacts on grid reliability, plant closures, and capacity losses. However, EPA did not analyze the impacts of its proposed options on the consumptive use of water. Similarly, EPRI has not conducted a detailed study of this question to date but did address the question generally in Ref 11, as discussed in Section 5.3.2 below. This chapter therefore refers primarily to studies conducted by NREL and NETL. It also points to the need for more detailed study of water consumption impacts on a watershed or regional basis.

Of these five cases above, Cases 2 and 5 are the most relevant to nuclear plants, for reasons discussed below for each case. NETL defines the rationale for these two cases as follows:

Case 2 represents a regulatory-driven situation under which NETL assumed that 316(b) and future regulations dictate the use of recirculating systems for all new capacity. Retirement decisions hinge on age and operational costs, rather than water source and type of cooling system. Under this case, EPA's Phase I requirements remain in effect for new plants, but current plant requirements revert back to the EPA's 2004 Phase II rule, which allowed for substantial site-specific flexibility in making once-through cooling vs. closed-cycle cooling decisions. Note that while the 2004 Phase II rule allowed for flexibility, there was nothing in that Rule to prevent the permitting authority from requiring a retrofit to closed-cycle cooling. Thus, Case 2 represents a situation where few currently operating facilities would be required by their permitting authority to convert to closed-cycle cooling.

Case 5 (the "conversion case") is the same as Case 2, except regulatory and public pressures compel state agencies to dictate the conversion of a significant amount of existing freshwater once-through cooling systems to wet recirculating. Although there is no direct connection between NETL's conversion assumption

for Case 5 (5% of existing fresh water once-through cooling capacity being retrofitted with wet recirculating cooling every 5 years starting in 2015, for a total of 25% conversion) to any assumption or requirement in the proposed EPA rule, this scenario represents a reasonable point of departure for estimating the impacts of wide-spread conversion of the existing fossil and nuclear fleets. As discussed later, this 25% conversion rate could represent either an under-estimate or overestimate of the actual impacts of the draft rule, in combination with a rate of conversions driven by permitting authorities or other factors not linked directly to required responses to the draft rule (i.e., unilateral NPDES actions).

Case 1 is defined by NETL as the "Status Quo" scenario case. It assumes that additions and retirements follow current trends. It represents a roll-back of Phase I rulemaking requirements for new plants such that current ratios of once-through vs. closed-cycle cooling remain in effect, and assumes no significant retrofitting of existing once-through facilities.

Case 3 is defined by NETL as the "Regulatory-light" case. New additions favor the use of freshwater recirculating systems, but some saline capacity using once-through cooling is permitted. Retirement decisions remain tied to age and operational costs, tracking current source withdrawals, which effectively assumes no significant retrofitting of existing once-through facilities.

Case 4 is defined by NETL as the "Dry cooling case." Regulatory and public pressures result in significant market penetration of dry cooling technology. Retirement decisions remain tied to age and operational costs, tracking current source withdrawals. As discussed in Chapter 2, this option is not feasible for nuclear plants, and was acknowledged as such by EPA in the proposed rule.

National Average Results: Because of the trend away from once-through cooling in all cases except Case 1, water withdrawal rates decline in Cases 2-5. As expected, water consumption rates increase in all five cases, with Case 5 providing the largest water consumption impacts. These results are driven by "... regulations and industry practice [in response to these regulations] which favor the use of fresh water recirculating cooling systems that have lower withdrawal requirements but higher consumption requirements than once-through cooling systems." For Case 5, the percent of total U.S. water consumption attributable to thermoelectric power plants rises by 28.4% by 2035.

Regional Results: The impacts on water consumption rates for these five cases are more dramatic when analyzed on a regional basis, with the greatest impacts evident in regions with high projected population growth and freshwater supply limitations. Table 5-1 highlights the EMM regions with the highest projected impacts on water consumption rates, focused on NETL's Case 2 and Case 5 scenarios.

Table 5-1 Selected Regional Water Consumption Data from NETL Report (Ref. 19)

% increase in Water Consumption, 2010-2035

	_000					
EMM Region	Case 2	Case 5	Impacted States (smaller portions of states in parentheses are included in the region)			
3-MROE	57	11 <i>7</i>	Wisconsin, (Michigan)			
7-NYLI	124	124	New York's Long Island			
15-SRCE	35	86	Kentucky, Tennessee, (Alabama)			
11-RFCW	17	55	Indiana, Ohio, West Virginia, (Virginia), (Pennsylvania), (Illinois), (Michigan), (Kentucky), (Maryland)			
13-SRGW	5	65	Missouri, Illinois			
14-SRSE	26	31	Alabama, Georgia, (Mississippi), (Florida)			
16-SRVC	14	40	North Carolina, South Carolina, Virginia			
1-ERCT	19	31	Texas			
4-MROW	12	30	North Dakota, South Dakota, Nebraska, Iowa, Minnesota, (Montana), (Wisconsin)			
5-NEWE	28	36	Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut			
8-NYUP	12	45	New York			
10-RFCM	16	35	Michigan			

How significant are these projected increases in water consumption? There is no overall answer to this question, since impacts will be regional-specific and often waterbody specific. For regions with ample year-round water resources and for thermoelectric generation cooled by ocean water, these consumptive impacts are not likely to be consequential. However, for water-stressed regions, and for water bodies that are susceptible to low flow or lowering water levels or drought during hot summer months, these increased consumption rates could create water use conflicts with other water users. More regional-specific or even site-specific studies are needed.

Note: the NETL report contains much more detail than presented here, including data for both withdrawal and consumption for all regions and all cases, with a breakdown for various fossil technologies.

Below is a U.S. map that displays the EMM regions developed by EIA. The map can be obtained from either Ref. 19 or the EIA website.

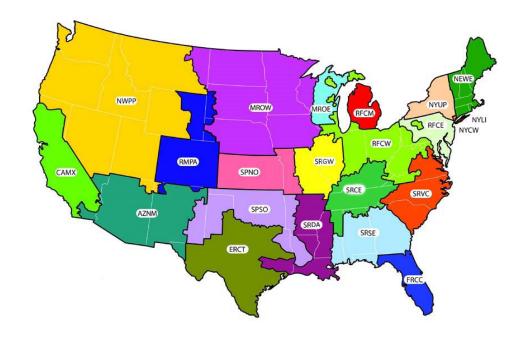


Figure 5-1 2010 Thermoelectric Water Consumption by EMM Region (Ref. 19)

5.3.2 EPRI Study Conclusions

EPRI's report, "Net Environmental and Social Effects of Retrofitting Power Plants with Once-through Cooling to Closed-cycle Cooling" [Ref. 12] addresses evaporative water loss as one of the impacts of retrofitting. In summary:

"Conversion to a closed-cycle cooling system will increase the evaporation rate compared to a once-through cooling system. Consumptive water loss from proposed closed-cycle cooling towers at modeled facilities is between ~400-900 gallons per megawatt (MW)-hr. electricity generation for fossil-fueled facilities and approximately 750-1,050 gallons per MW-hr. for nuclear facilities, which is over double the water loss estimated for once-through cooling ...Nationally, the total estimated freshwater evaporative loss is estimated to be 500 billion gallons/yr. (372 billion gallons/yr. for facilities on large rivers, reservoirs and lakes other than the Great Lakes and 128 billion gallons/yr. for facilities on the Great Lakes and small rivers). Note that permitting and/or the issue of obtaining additional water rights to maintain water levels for cooling lakes and ponds in southwestern arid portions of the United States such as Texas and Oklahoma are not evaluated in the study."

The methodology for quantifying the effects of retrofitting relied on plant specific analyses of five Beta Test Plants (BTPs) and four Reference Facilities (RFs) used throughout the EPRI report series. Two of these nine plants were nuclear plants. For these two plants, the estimated annual average in-stream evaporation rates were 9,600 gpm and 13,100 gpm (averaging to 11,350 gpm). In general, the difference in evaporation between once-through cooling and closed-cycle cooling is greater in lower wet-bulb locations (i.e., in the western half of the U.S. and the northern U.S.). Therefore, retrofitting once-through facilities with cooling towers could increase consumptive loss of water in already drier locations. From Ref. 12:

"The evaporative loss due to the installation of mechanical-draft evaporative cooling towers may result in reductions in the availability of potable water, a decrease in water surface elevation on rivers and lakes and corresponding loss of aquatic and riparian habitats and recreational uses, and a decrease in the assimilative capacity of the river. The magnitude of these possible impacts would correspond to the percent of the water loss relative to the in-flow. Note that evaporative loss from plants located on large waterbodies is less likely to be a significant issue."

"Additional evaporative loss from mechanical-draft evaporative cooling towers may be exacerbated during drought conditions. The declaration of drought conditions by a state or regional water resources authority is driven by regional or local stream flows or water surface elevations. The increase in consumptive water use resulting from cooling towers may increase the frequency of drought declarations in the watersheds of the source waterbodies."

On an individual plant basis, the effects of evaporative loss to total flow rates and water levels in the source waterbody were minimal. WTP monetization was based on potential changes in water levels to the extent that recreational activities (boating, fishing, etc.) would be impacted. However, the methodology did not evaluate the impacts of evaporative loss on the competition among water users (e.g., municipal water supplies, agricultural use); nor did it evaluate the cumulative effects of multiple retrofitting or new plant construction on a regional basis. One additional economic impact on plants in dry regions is the cost of water rights. Many power companies own or buy water rights for their facilities. These water rights can be substantial and could approach the cost of building and operating a cooling tower. These costs, which can range up to \$7,500 per acrefoot, would need to be accounted for in a cost-benefit analysis.

EPRI's report, "Water Use for Electricity Generation and other Sectors: Recent Changes (1985-2005) and Future Projections (2005-2030), EPRI Report 1023676; [Ref. 25] provides additional insights for water usage trends. This report focuses on water withdrawal, available water resources and forecasts future trends relative to those resources, thus providing helpful context for water consumption that is more the focus of this report. This study documents that

water in some regions of the U.S. is already in short supply and is forecasted to get worse to 2020. One of the conclusions from this report states:

"Future projections of water withdrawal and water availability were composited into an index that compared, on a relative basis, the water supply sustainability risks through the U.S. Metrics considered in the index include the extent of water development already in place, dependence on groundwater, the region's susceptibility to drought, projected increases in water use, and the difference between peak summer demand and available precipitation (a measure of storage requirements). The water supply sustainability risk index shows that the most significant future water stresses are in the Southern/Southwestern U.S., and in the Great Plains states. When the locations of existing power generation facilities are overlaid on the map of the index, roughly 250,000 MW of generation, or about a quarter of the U.S. total, are in counties that are associated with some type of water sustainability concern. It is likely that no matter what future water withdrawals are, water sustainability constraints will emerge not during average flow years, but during years of below-normal precipitation. However, pressure for supplies during average rainfall years is a strong indicator of the potential of sustainability risk when rainfall is below average."

The report also points out that improved efficiency in water use and conservation will be important areas of focus to ensure adequate future water supply.

5.4 Discussion

The following discussion relates the above review of consumptive water use to the proposed 316(b) rule, and specifically to how a conclusion that closed-cycle cooling technologies are estimated to consume twice as much water as once-through cooling might impact various scenarios under that rule.

In terms of 316(b), it is currently unclear how many facilities will be required to retrofit under EPA's Proposed Rule. Important considerations relative to 316(b) as a potential driver of closed-cycle cooling retrofits and the resulting increase in consumptive water use include:

- The BTA decision on entrainment specifically requires evaluation of closed-cycle cooling for facilities that use more than 125 MGD actual flow, which would include all nuclear facilities. The permitting authorities' BTA decision on closed-cycle cooling will be based on consideration of the cost, benefits, potential reliability impacts and environmental impacts. It is anticipated that some retrofits may be required.
- While the impingement mortality reduction requirements are not based on closed-cycle cooling as BTA, it is unclear whether or not closed-cycle cooling retrofits could be required, if a facility could not comply with the biological compliance monitoring criteria to limit impingement mortality to 12% annually and 31% monthly and could not reduce the maximum through

screen design velocity to not exceed 0.5 fps. Thus, some plants may be forced to consider retrofitting closed-cycle cooling as the only means of complying with impingement requirements.

Additionally, some state or EPA Regional NPDES permitting authorities have already initiated processes to require existing thermoelectric facilities to install closed-cycle cooling (New York, California, Delaware, and New England). Although these states have taken this action on their own, these decisions may result in increased consumptive use of water in the impacted states. Also note that the proposed rule includes an implicit encouragement for other permitting authorities to follow suit: "EPA supports these state efforts and determinations and thinks that similar decisions would be able to be made under this proposed rule." (at 76 Fed. Reg. 22210)

EPA could select Options 2 or 3 (both based on close-cycle cooling as BTA), in which case the impacts on consumptive water use could be much greater than any of the cases analyzed by NETL. Options 2 or 3 would result in a consumption rate increase of roughly 100% on a national average basis and regional increases ranging from 120% to over 400% for the EMM regions identified in the table above. ¹² The potential costs, financial, reliability and environmental impacts of Options 2 or 3 are estimated in EPRI's Closed-cycle Cooling Retrofit Research Program, and were summarized in Chapter 4.

As discussed in Chapter 2, proposed changes to the existing facilities 316(b) rule carefully evaluated a wide range of societal impacts that would result from the four options considered, including impacts on grid reliability, plant closures, capacity losses, etc. However, EPA did not evaluate the impacts of designating closed-cycle cooling as BTA (i.e., Options 2 and 3) on consumptive water use and the resulting issues associated competing water needs from different stakeholders.

The result of the combined concerns over water availability, thermal issues and CWIS impacts as drivers for use of closed-cycle cooling for new and existing facilities has potentially significant implications for future consumptive water use. Failure to consider these implications may adversely affect future water use in some regions of the U.S.

 $^{^{12}}$ These estimates are based on multiplying the Case 5 results by four. Case 5 assumes an eventual conversion rate of 25% of existing facilities to closed-cycle cooling, so 4 X 25% approximates the impacts of 100% conversion.

Section 6: Impacts of Once-Through Cooling to Fish and Aquatic Life

This Chapter provides information on the level of adverse impacts, or conversely the benefits of addressing them, so that they can be compared to the cost and environmental and social impacts of retrofitting the 39 once-through cooled nuclear power plants with closed-cycle cooling. Thermal and cooling water intake structure impacts are discussed.

6.1 Thermal Discharge

As discussed in Section 2.4.1, heat is unique as a pollutant, in that it is physical rather than chemical in nature and is temporary rather than persistent once it is introduced into the water. A number of facilities, including some nuclear power plants, are unable to meet the thermal water quality criterion for heat in their receiving waterbody, and have sought 316(a) thermal variances. The result is that a significant body of work on the effects of thermal discharges on fish and other aquatic life has been generated and reported in 316(a) Demonstration Reports submitted to request alternate thermal effluent limitations. The majority of the facilities were successful in obtaining thermal variances. However one nuclear facility, the Palisades Power Plant in Michigan, was required to retrofit to closed-cycle cooling to address thermal concerns.

Two-thirds of the 39 nuclear facilities using once-through cooling have an approved site-specific §316(a) variance "...that will assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on that body of water." The other one-third of these facilities meets the thermal discharge criteria set by the permitting authority for facilities within their jurisdiction, and do not need a site-specific variance.

6.2 Cooling Water Intake Structures

This Section provides an overview of current levels of impingement and entrainment resulting from nuclear power plants (6.2.1) and the impacts from those losses to the source waterbody (6.2.2).

6.2.1 Current Level of Impingement and Entrainment at Nuclear Facilities

EPRI created a database from impingement and entrainment studies conducted for compliance with the now remanded Phase II Rule. Companies submitted a summary of their impingement and entrainment data along with information on the facility, the study methods, the method used to estimate annual impingement and entrainment as well as other parameters. Impingement data for 166 facilities and entrainment data for 90 facilities were provided. Under the Phase II Rule, facilities that withdrew cooling water from a river and used less than 5% of the mean annual flow and those located on freshwater lakes, other than the Great Lakes, or reservoirs were not required to conduct entrainment characterization studies. Facilities were asked to estimate the total annual impingement and entrainment losses based on actual cooling water flow. They were also asked to input annual estimates of impingement and entrainment for the top 10 species of fish and shellfish impinged and entrained. A complete description of the study methods and findings is provided in EPRI Technical Report 1019861 [Ref. 14]. Seventeen (or 44%) of the 39 nuclear facilities provided a summary of their impingement data and eight (or 25%) provided a summary of their entrainment data. Direct comparisons between facility loss numbers were not made, since to be meaningful, such comparisons require converting entrainable life stages into equivalent age 1 or equivalent adult organisms. That was a subject of EPRI Technical Report 1023401 [Ref. 13], and is discussed below in Section 6.2.2.

6.2.2 Impacts on the Source Waterbody

The CWA 316(b) statutory language requires facilities to minimize "adverse environmental impact" (AEI). However, what constitutes AEI has never been defined and has been the subject of extensive debate. Some argue that one dead fish is an AEI, while others consider it a population level impact that poses a threat to the population's sustainability. It is a subject that EPRI has studied from a technical standpoint. A summary of that information is provided in Sections 6.2.2.1 through 6.2.2.4.

In July 2011 EPRI completed technical report 1023094 titled "Do Power Plant Impingement and Entrainment Cause Adverse Changes in Fish Populations? A Review of the Scientific Evidence." [Ref. 26] The approach focused on six sources of information that included:

- 1. Peer-reviewed literature from studies on impingement and entrainment impacts from power plants on fish populations
- 2. Peer-reviewed technical papers in the scientific literature linking impingement and entrainment to reductions in freshwater or marine ecosystem services
- 3. Papers in the scientific literature linking impingement and entrainment to reductions in freshwater or marine ecosystem services

- 4. "Blue-ribbon" commission reports such as the Pew Ocean Commission report and relevant National Academy of Sciences Reports that discuss causes of fish population decline and marine ecosystem degradation
- 5. EPA's reports on the condition and causes of degradation of coastal ecosystems
- 6. Peer-reviewed papers and agency stock assessment reports documenting the causes of declines in marine and freshwater fish populations.

While the literature survey did not specifically focus on nuclear facilities, they were included in the scope of this project. A number of sources were identified including Pew Oceans Commission and National Research Council Blue Ribbon Panels and EPA National Research Council documents. Significant issues cited as threats to coastal fisheries included overfishing, habitat alternation, nutrient enrichment, invasive species and non-point source pollution. However, impacts from cooling water intake structures were never mentioned as a threat to fisheries. Sixteen studies were found with specific reference to cooling water intake structures. Three of those were retrospective studies that found no impacts. Seven of the studies were modeling studies, four finding no impact and three finding a potential for impact. Four studies focused on equivalent adult losses from impingement and entrainment and all four found those losses were negligibly small compared to fishery harvests. Two of the studies focused on cumulative impacts; and both were found to be inconclusive, with one concluding that it was currently not possible to develop a reliable cumulative impacts estimate because the requisite data to perform the assessment were not available.

The Supreme Court decision on whether or not the EPA could consider cost relative to benefits in making the BTA determination was issued in April 2009. That decision determined that EPA could consider the benefits in context with the costs to establish the BTA standard and EPRI initiated research to estimate the national benefit to commercial and recreational fisheries of closed-cycle cooling as BTA for existing facilities. The results of that research were entered into the public record during the 316(b) existing facilities comment period in EPRI Technical Report 1023401 [Ref. 13]. EPRI's approach involved use of its impingement and entrainment database and a number of site-specific 316(b) benefit valuation studies. Specifically, EPRI acquired 70 impingement and/or entrainment site-specific benefit valuation estimates and generated another 34 impingement and entrainment mortality reduction estimates. The methods used to estimate the benefit assumed a 95% reduction in impingement and entrainment would be achieved. The biological and economic assumptions were based on methods very similar to those used by the EPA to estimate the benefits of the Phase II Rule and proposed Existing Facility Rule.

The methods for converting the facility-level estimates into the national benefit estimates used EPRI's list of 428 Phase II facilities (including the 39 nuclear facilities) and allocated those facilities into three tiers based on the information available for the facility. Tier 1 facilities were estimated with the site-specific benefit estimates that were either acquired or generated by EPRI. Facilities in Tier 2 had current (i.e. collected for compliance with Phase II Rule) quantitative

impingement and/or entrainment sampling data results. EPRI found there was an acceptable correlation between the numbers of organisms impinged and/or entrained in the database and the site-specific economic benefit estimates. Thus Tier 2 estimates were made for all facilities in the EPRI Phase II Facility Database for which no site-specific impingement and entrainment mortality reduction benefit had been generated. Tier 2 consisted of 127 facilities with impingement data and the 45 facilities with entrainment data. For the remaining facilities (196 facilities for impingement and 313 facilities for entrainment) that were not in the EPRI database and had no site-specific benefit estimates, the benefit estimate was based on a statistical model of the relationship between plant design flow and the acquired or generated site-specific benefit estimates. Thus, the national benefit estimate is the sum of the existing benefit valuation studies, the site-specific benefit valuation studies, the estimated benefits for facilities with I&E data, and the estimated benefits for facilities without impingement and entrainment data.

This total estimated national annual benefit was \$16 million from retrofitting all existing Phase II facilities with closed-cycle cooling. This estimate includes the economic benefit to commercial fisheries based on the expected increase in commercial harvests and the increased willingness to pay by recreational fishermen due to their expected increased catch per fishing trip. The national benefit from retrofitting the 39 nuclear once-through cooled facilities was estimated to be \$2.9 million/yr. or just under 18% of the total annual impingement and entrainment mortality reduction benefit estimate. Based on the annualized cost to retrofit the nuclear facilities with closed-cycle cooling of \$2.28 billion/yr. (includes capital cost, lost revenue due to an extended outage, energy penalty and heat rate penalty), the annualized cost is 792 times greater than the annual benefit. The benefit estimate was based on the commercial and recreational fishing benefit and did not include non-use benefits. However, this comparison also excludes the monetized economic costs associated with the environmental and social impacts of closed-cycle cooling discussed in section 4.4.1.

6.3 Insights from NRC Environmental Reviews

The following summary of the Nuclear Regulatory Commission's (NRC's) environmental review process and results relative to cooling water issues is taken from Ref. 4. The text has been updated and shortened, with less detail on the NRC licensing processes, particularly related to new plant licensing, and omission of site-specific details. See Ref. 4 for a more complete discussion.

6.3.1 NRC's Environmental Review Process

As part of its responsibility to license nuclear facilities in the U.S., the NRC has a role in assessing environmental protection issues. NRC's authority and obligation under federal law to assess the environmental impacts of its decisions comes from the National Environmental Policy Act (NEPA), which specifies that a "...major Federal action significantly affecting the quality of the human environment requires a detailed statement on, among other things, the environmental impact

of the proposed action and alternatives to the proposed action. The statement is to accompany the proposal through the agency review process. The Act also established in the Executive Office of the President a Council on Environmental Quality, which has issued regulations on the preparation of environmental impact statements and on public participation in the preparation of the statements." NRC has determined that the license renewal of an existing nuclear reactor and the licensing of a new nuclear reactor both constitute "major Federal actions." This in turn invokes the processes described below, quoted or paraphrased from the NRC website sections on "Reactor License Renewal" and "New Reactors."

License Renewal: "The NRC has established a timely license renewal process and requirements, codified in 10 CFR Part 51 [Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions] and 10 CFR Part 54 [Requirements for Renewal of Operating Licenses for Nuclear Power Plants], that are needed to assure safe plant operation for extended plant life. The timely renewal of licenses for an additional 20 years, where appropriate to renew them, may be important to ensuring an adequate energy supply for the United States during the first half of the 21st century."

New Reactors: "For new reactor facilities, the NRC reviews applications submitted by prospective licensees, and (when appropriate) issues standard design certifications, early site permits, limited work authorizations, construction permits, operating licenses, and combined licenses. Of the NRC's existing regulations, the following are most relevant to the design, siting, construction, and operation of new commercial nuclear power facilities:

- 10 CFR Part 51, "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions"
- 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants"

"Under the NRC's regulations in 10 CFR Part 52 and in accordance with the applicable provisions of 10 CFR Part 51, which are the NRC regulations implementing the National Environmental Policy Act (NEPA), the NRC is required to prepare an environmental impact statement (EIS) as part of its review of an early site permit (ESP) or combined license (COL) application. ... The NRC staff currently conducts its environmental reviews using NUREG-1555, "Environmental Standard Review Plan" (ESRP)."

6.3.2 NRC Review and Approval of Nuclear Plant Cooling Water Systems:

Based on the above requirements that "major Federal actions" such as initial licensing or re-licensing of a nuclear plant be reviewed to ensure conformance to the National Environmental Policy Act, the NRC reviews the cooling water systems of all nuclear plants for conformance to Federal environmental

requirements, including EPA requirements, in addition to its own nuclear safety requirements. These safety and environmental reviews are done in parallel; and NRC authorization for initial operation (or continued operation during a license renewal period) is granted only after both safety and environmental requirements are met.

In the case of license renewal, an applicant must submit a detailed application under Part 54 for the plants design and operation, and a separate application under Part 51 for its compliance with NEPA. In the case of new plants, the applicant has options. Part 52 was designed for the baseline case in which an applicant applies for an "Early Site Permit" (ESP) without a commitment to a particular design or construction plan. Separately, standardized reactor designs are submitted by reactor vendors for safety review and approval by NRC via a rulemaking process ("Design Certification" or DC). An owner-operator, would then take the approved site (previously approved by NRC using the Part 52 ESP process) and a certified reactor design, and merge them into an integrated application to construct and operate that design on that site (the "Combined License", or COL). However, Part 52 gives the applicant the flexibility to combine these steps in various ways or to pursue them in parallel instead of in series, albeit with some increased regulatory risk. In all cases, the environmental reviews are included in either the ESP or the COL process. Also, the ESP and DC reviews and approvals, including public hearing and comment periods prescribed by law, must be completed before the COL is issued.

For both new plant and license renewal reviews, the NRC provides generic guidance to applicants on the required content of their site specific Environmental Reports, primarily via NUREG-1555 (Standard Review Plan) and NUREG-1555, Supplement 1: Operating License Renewal, respectively, and supporting Regulatory Guides. In addition, NRC conducted a formal generic evaluation of environmental issues relevant to License Renewal, to narrow the scope of information that needs to be provided. This generic evaluation, NUREG-1437, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants" (GEIS) was issued in 1996. The NRC then issues a site-specific Supplement to this GEIS (the EIS) to report its findings and conclusions on each Environmental Review.

Under the GEIS process, the NRC staff identified 92 environmental issues and reached generic conclusions related to environmental impacts for 69 of these issues that apply to all plants or to plants with specific design or site characteristics. Additional plant-specific review is required for the remaining 23 issues. These plant-specific reviews are to be included in a supplement to the GEIS.

The GEIS evaluated all 92 environmental issues using the NRC's three-level standard of significance—small, moderate, or large—developed using the Council on Environmental Quality guidelines:

• Small—Environmental effects are not detectable or are so minor that they will neither destabilize nor noticeably alter any important attribute of the resource.

- Moderate—Environmental effects are sufficient to alter noticeably, but not to destabilize, important attributes of the resource.
- Large—Environmental effects are clearly noticeable and are sufficient to destabilize important attributes of the resource.

For 69 of the 92 issues considered in the GEIS, the GEIS analysis reached the following conclusions:

- 1. The environmental impacts associated with the issue have been determined to apply either to all plants or, for some issues, to plants having a specific type of cooling system or other specified plant or site characteristics.
- 2. A single significance level (i.e., small, moderate, or large) has been assigned to the impacts (except for collective offsite radiological impacts from the fuel cycle and from high-level waste and spent fuel disposal).
- 3. Mitigation of adverse impacts associated with the issue has been considered in the analysis, and it has been determined that additional plant-specific mitigation measures are not likely to be sufficiently beneficial to warrant implementation.

These 69 issues were identified in the GEIS as Category 1 issues. In the absence of new and significant information, the NRC staff relied on conclusions in the GEIS for issues in Category 1.

Of the 23 issues that do not meet the criteria set forth above, 21 are classified as Category 2 issues requiring analysis in a plant-specific supplement to the GEIS. The remaining two issues, environmental justice and chronic effects of electromagnetic fields, were not categorized.

Of the 92 issues, 40 relate or could relate to water issues in four broad categories:

- Surface Water Quality, Hydrology, and Use (for all plants)
- Aquatic Ecology (for plants with once-through and cooling pond heat dissipation systems)
- Ground-water Use and Quality
- Threatened or Endangered Species (for all plants).

Of the 40 issues potentially related to water, ten have been determined to potentially involve moderate or large environmental impacts at some sites and thus require site-specific evaluation. Those ten issues include impingement, entrainment, heat shock, ground water impacts, threatened or endangered species considerations, etc.

6.3.3 Current Status and Findings

As of the publication date of this report, 71 individual reactor units have been reviewed and approved for license renewal. Another 15 reactors are under review, at various stages of completion. Of these 15, six have proceeded far enough in the review process to have received from NRC their EIS or Draft EIS for public

comment. Therefore, 77 reactors (74% of the U.S. fleet) have either completed environmental review or are sufficiently complete to have received an initial assessment from NRC with regard to findings on the ten water-related issues.

Of these 77, all but 12 plants at nine sites have been determined to have small environmental impacts. Of the 65 reactors that have been judged to have small environmental impacts, 51 use once-through cooling.

The remaining 12 reactors were found to create moderate (or small to moderate) environmental impacts, primarily in one or more of the ten site-specific water-related categories. The areas of concern for most of these plants were in one or more of the "Aquatic Ecology" issues, most frequently impingement or entrainment.

All of the reactors with moderate impingement and entrainment issues are in an ocean, estuary, or tidal river (O/E/TR) environment. However, it is important to note that not all reactors in O/E/TR environments have issues with impingement and entrainment: Thirteen reactors at O/E/TR sites have been judged to have small environmental impacts. Twelve of these 13 reactors use once-through cooling on O/E/TR sites. In summary, NRC has determined, based on NEPA criteria, that over 60% of reactors on O/E/TR sites that have been evaluated to date for license renewal exhibit small environmental impacts.

6.3.4 Discussion

A finding of moderate on a few issues has not been disqualifying for license renewal, which assesses the overall environmental impacts in all areas against alternatives, as well as all the reactor safety issues (issues related to aging of plant structures, systems and components, etc.) A number of plants have successfully renewed their operating licenses with one or two issues judged as presenting moderate impacts.

Each of these environmental reviews is conducted in consultation with Federal, state and local agencies, including EPA and state water permitting authorities. NRC's environmental review is based on NEPA regulations and its GEIS, as discussed above. NRC's application of NEPA is in accordance with NEPA and CEQ's implementing regulations, and allows for consideration of the impacts on the source waterbody as a whole. Even though acceptance criteria differ among these agencies, the findings and recommendations of the NRC do reflect the input of EPA and state authorities.

The NRC's interpretation of NEPA requires the staff to assess the environmental impacts of cooling water issues on the overall environment in a holistic manner. This means the NRC strives to assess AEI on the source waterbody, as opposed to inferring AEI based on extrapolating entrainment and impingement data. This approach can be more difficult or subjective in terms of data collection and interpretation, but may provide an indication of true impacts on the ecosystem.

The NRC's approach is very site-specific. The generic portion of its Part 51 process is applied only to help eliminate environmental issues that are not applicable or that can be easily demonstrated to be of no concern. Any environmental issue of potential significance is fully assessed on a site-specific basis. Stakeholder inputs to NRC are strongly site-specific.

The NRC does not employ rigid acceptance criteria. Rather, it utilizes the rankings provided under NEPA for "small," "medium," and "large" impacts, and assesses the adequacy of environmental protection accordingly.

The owner/operator must demonstrate acceptable environmental performance. If the NRC determines that performance is inadequate, it is the responsibility of the owner/operator to propose alternate technologies or actions to mitigate the AEI. The owner/operator can consider costs and benefits in proposing its approach to address AEI.

Section 7: Use of Alternative Fish Protection Technologies as BTA for Nuclear Facilities

The purpose of this Chapter is to summarize currently available fish protection technologies and operational measures that have the potential to reduce impingement and/or entrainment. It is generally the case that any entrainment reduction technology will also reduce impingement. A summary of the existing use of alternative fish protection technologies and operational measures at nuclear power plants is provided, followed by an overview of technologies that could reduce impingement mortality and entrainment mortality. Each of the fish protection technologies discussed can vary significantly in terms of performance, practicality and cost on a site specific basis. EPRI's report on fish protection at cooling water intakes [Ref. 27] provides a much more detailed discussion of the alternative fish protection technologies and operational measures.

Over the last two to three decades, the power industry has developed a wide range of technology options that are proving to be highly effective in reducing CWIS impingement and entrainment, particularly in the impingement category. Many of these technology options were not available or adequately developed back in the 1980s when cooling towers became more prevalent. For impingement mortality reduction, these technologies often provide equivalent aquatic life protection performance to cooling towers, depending on site-specific and species-specific factors. For entrainable life stages, the available technologies are more limited. However, relatively good performance can be achieved depending on site-specific factors and the life stage of the organisms vulnerable to entrainment.

7.1 Existing Use of Fish Protection Measures at Nuclear Facilities

Nearly a third of the 39 once-through cooled nuclear power plant sites currently employ either some form of impingement and/or entrainment reduction technology and/or have instituted environmental mitigation measures to offset impingement and entrainment losses. The list of these facilities and a summary of the fish protection actions is as follows:

- 1. **Brunswick Nuclear Plant** Brunswick uses a combination of a fish diversion structure at the entrance to the intake canal combined with modified traveling screens to reduce impingement mortality by >90%.
- 2. Crystal River The Crystal River complex incorporates four fossil units and one nuclear unit. Fossil Units 1&2 and nuclear Unit 3 are once-through cooled; fossil Units 4&5 are closed cycle-cooled. Florida Power Corp. opened the Crystal River Mariculture Center in 1991, a multi-species marine hatchery intended to mitigate impacts of the Crystal River plant's once-through cooling system. The Mariculture Center includes an 8,100 square foot hatchery building with four spawn rooms and eight one-acre grow-out ponds. (Note 1)
- 3. **D.C. Cook Nuclear Plant** This facility has installed a high frequency acoustic deterrent system to reduce impingement of alewife, a dominant impingement species. D.C. Cook has evaluated the benefits of installing an off-shore intake. Under the Phase II Rule's calculation baseline, D.C. Cook would have reduced impingement mortality by 98% and entrainment mortality by 86% as a result of locating the intake off shore rather than at the shoreline.
- 4. **Indian Point** Indian Point Units 2&3 use modified vertical Ristroph traveling screens. Key fish-protection components are screen basket lip troughs designed to retain water and minimize vortex stress, a low-pressure spray wash system for fish removal from the rear side of the machine, and a fish sluice system for collection of the impinged fish for return to the river. Indian Point also uses dual or variable speed intake pumps to minimize flow rates.
- 5. James A. Fitzpatrick The James A. Fitzpatrick Nuclear Station is equipped with a submerged offshore velocity cap to reduce impingement. Impingement at this facility was dominated by alewife and as further protection for this species an acoustical fish deterrent (AFD) system was installed, reducing alewife impingement by more than 90%. Fitzpatrick has also added modified Ristroph screens.
- 6. **Nine Mile Point Nuclear Power Station** Unit 1 of the Nine Mile Point Nuclear Generating Station is equipped with a submerged offshore velocity cap to reduce impingement mortality. Unit 2 uses closed-cycle cooling.
- 7. **Prairie Island Nuclear Power Plant** Prairie Island employs use of 0.5 mm fine mesh modified traveling water screens (low pressure wash, fish buckets, continuous screen rotations and a fish return system) when entrainable fish life stages are present from the beginning of April through the end of August. Additionally, during these months the maximum through screen velocity does not exceed 0.5 fps, providing a benefit to both impingeable fish.
- 8. **Point Beach Nuclear Plant** Point Beach installed a high frequency acoustic deterrent system to reduce impingement of alewife, a dominant impingement species.
- 9. **Quad Cities Generating Station** This facility engages in an aquaculture program that raises walleye and hybrid striped bass for stocking in the

Mississippi River that mitigates impingement losses at the CWIS. As of mid-January 2012, over 7 million fingerling walleye, 600,000 fingerling hybrid striped bass, and nearly 70,000 yearling hybrid striped bass have raised and stocked in the Mississippi River. In 2011 alligator gar were added to the program.

- 10. **R. E. Ginna Nuclear Station** The R. E. Ginna Nuclear Station is equipped with a submerged offshore velocity cap to reduce impingement mortality.
- 11. Salem Nuclear Power Plant Salem's CWIS is equipped with enhanced Ristroph-modified traveling screens with a fish return system. This technology was identified as BTA for impingement in the proposed §316(b) rule for impingement mortality reduction. Additionally, to offset CWIS losses, some 20,000 acres of degraded salt marsh and adjacent uplands were restored, enhanced or preserved, greatly increasing aquatic production in the Delaware Estuary. Just three of the seven wetland restoration sites are estimated to produce 3.9 times the secondary consumer biomass potentially lost due to entrainment at the Salem CWIS. (Note 1)
- 12. **Seabrook Station** Seabrook is equipped with a submerged offshore velocity cap to reduce impingement mortality.
- 13. **St. Lucie Nuclear Power Plant** St. Lucie is equipped with a submerged offshore velocity cap to reduce impingement mortality. The facility has also added a small mesh barrier net to prevent sea turtles from entering the intake canal.
- 14. San Onofre Nuclear Generating Station (SONGS) Studies conducted in California have demonstrated that SONGS has existing technologies that reduce impingement mortality by an estimated 94.2% for finfish (97.7% by weight). Impingement mortality reduction is achieved through the use of an offshore intake with a velocity cap combined with an on-shore fish return system (FRS). In addition to modifications to the intake structures, Southern California Edison has committed to restore 150 acres of coastal wetland, costing \$86 million. This acreage was determined by the California Coastal Commission (CCC) to be sufficient to offset entrainment losses of Units 2 and 3. Recent California regulations have required that all power plants convert to closed-cycle cooling, but the two nuclear plants in California will be subject to an independent, specific analysis of cost/benefit that is currently being scoped. (Note 1)

Note 1: These plants use restoration or remediation strategies that replenish fish stock lost via CWIS impacts. These strategies include construction of fish hatcheries and/or natural spawning grounds such as marshes and wetlands. However, as discussed in Chapter 2, the Second Circuit Court of Appeals determined in 2007 that use of restoration measures could not be used as a compliance option. The Supreme Court reversed other Second Circuit opinions, but did not address the issue of restoration. Thus, EPA cannot consider restoration as a compliance measure. Despite this, some states either require or give credit for restoration activities.

7.2 Alternative Fish Protection Technologies to Reduce Impingement Mortality

There are a variety of alternative fish protection technologies and operational measures available to reduce impingement mortality. The practicality, cost, and performance of these technologies tends to be very site specific, due to their variability in terms of performance for species of concern, hydraulic conditions and water depth in the vicinity of the intake, waterbody type and uses, and other factors. A brief summary of technology categories is provided below, based on details in Ref. 27.

7.2.1 Exclusion Technologies

Exclusion technologies function by keeping fish and other aquatic life from entering the cooling water intake structure. This is accomplished by using a combination of a physical barrier such as a screen and sufficient surface areas to achieve a through screen velocity that does not exceed 0.5 fps. Examples include use of cylindrical wedgewire screens or barrier nets. The same result can be achieved with conventional traveling screens where there is sufficient screen surface to maintain the through screen velocity below 0.5 fps. The barrier net is generally the lowest cost exclusion technology, but it may have higher maintenance costs. There are over a dozen deployments in the U.S. at fossil facilities, but none at nuclear facilities. They are best suited for use in protected waters such as freshwater lakes, reservoirs and tidal waters. Their primary disadvantage is that they tend to be labor intensive and net changes may be required twice per week in tidal waters to control biofouling. Due to deployment in the source waterbody, navigation obstruction can also be an issue.

Wedgewire screens have been deployed at a number of fossil facilities and come in a variety of sizes. They can be designed for offshore deployment on the bottom of the source waterbody or from a bulkhead along the shoreline. The surface area can be kept clean and free of biofouling through use of compressed air (airblast), mechanical cleaning or manual cleaning. Major issues that may preclude application at certain sites are lack of adequate water depth, high debris loading (including frazil ice), low or varying ambient current velocity, navigation issues, and open ocean deployment. Cylindrical wedgewire screens are also one of the highest cost alternative fish protection technologies.

7.2.2 Fish Collection and Transfer Technologies

Fish collection and transfer technology was identified by the EPA as BTA for impingement mortality reduction. The technology is based on use of conventional traveling water screens that have been modified to maximize the survival of fish and shellfish collected on the screens, and to transport them back to the source waterbody to a location outside the zone of hydraulic influence of the cooling water intake structure. Mortality is minimized by continually rotating the screens and transferring collected fish to a fish return sluiceway, where they can be returned to the source waterbody in as short a time as possible. There are a variety of types of modified traveling screens, including Ristroph-modified

traditional band, Passavant-Geiger Rotary screen, Hydrolox molded polymer screen, and Beaudry Water Intake Protection (WIP) vacuum screen.

Ristroph modified traditional band screens were the first screens developed with fish protection characteristics and has been most widely used. Recently there has been increased use of Passavant-Geiger Rotary screens as they also eliminate carryover of debris that can cause condenser blockage. The Beaudry WIP traveling screens are unique in that fish are vacuumed off the screens while underwater and transported with a Hidrostal fish pump back to the source waterbody. EPRI studies at Omaha Public Power District's North Omaha Station (EPRI Technical Report 10184900; Ref. 28) found the technology had very high survival rates, with no significant difference in survival between the test organisms and controls.

There are two other design concepts that have undergone laboratory testing and have the potential to significantly reduce impingement mortality. These are the modular inclined screen (MIS) and "AquaSweep" system. The MIS consists of a flat panel wedgewire screen inclined at a 15 degree angle in an intake tunnel. While cooling water passes through the 2 mm screen, fish and shellfish are carried up the inclined panel and collected into a fish collection pipe where flow provided by a Hidrostal fish pump transports them back to the source waterbody. This technology avoids the need for fish to be impinged on traveling screens for collection.

AquaSweep consists of a single vertical flat panel wedgewire screen placed in front of the cooling water intake structure and perpendicular to the cooling water flow. River flow in the case of facilities located on free flowing rivers or induced flow generated by a large fish friendly pump, generate a flow parallel to the flat panel wedgewire screen that exceeds the flow velocity through the flat panel screen. The result is that impingeable sized organisms are transported past the flat panel wedgewire screen rather than being impinged on it.

7.2.3 Velocity Caps

There are currently six nuclear power plants equipped with velocity caps which have been shown to significantly reduce impingement mortality. They work by generating a flow field that many species of fish can detect and then avoid. In California there are six facilities with velocity caps, one of which is nuclear, and they have the capability to reverse flow to control biofouling in the intake tunnels. The discharge pipes are open pipes without velocity caps. Studies were done to compare impingement rates from withdrawing water through the open discharge pipe to withdrawing water through the velocity cap. The most recent such study conducted at the Scattergood Generating Station in 2006/2007 demonstrated greater than 95% reduction in impingement mortality with the velocity cap. Earlier studies at three other California coastal facilities had impingement reduction results ranging from 53 to 99%.

7.2.4 Velocity Reduction

EPRI conducted a study [Ref. 29] of the relationship of approach velocity and fish swim speeds. Figure 7-1 summarizes the results of 536 independent data points of studies conducted for various fish species and size ranges in response to velocity. The results show that at a through screen velocity of 0.5 fps (approach velocity of 0.25 fps) there is only one data point below the threshold, suggesting that a through screen velocity of 0.5 fps is highly protective for all impingeable species and life stages. EPRI also found that for facilities that impinge larger size ranges, a higher through screen velocity could provide equally protective results. Further, these data indicate that, in general, reducing velocity reduces the potential for impingement.

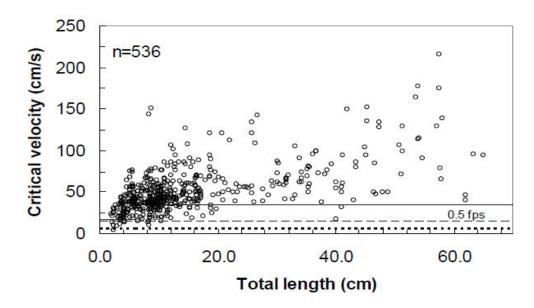


Figure 7-1 Critical fish swim speeds relative to water velocity based on 536 data points for various fish species and size ranges. (Ref. 29)

7.2.5 Fish Diversion Systems

Diversion systems have also been shown to be an effective means for reducing impingement for many fish species. As noted above, the Brunswick Nuclear Station employs a diversion system at the entrance to the intake canal that, combined with modified traveling screens and a fish return, have reduced impingement by more than 90%.

7.2.6 Flow Reduction

An EPRI study of the relationship between flow and potential for aquatic impacts (EPRI 2003; Ref. 30) conducted by the Oak Ridge National Laboratory did not find a clear dose-response relationship between flow withdrawals and the status of fish populations. However, the EPA, in the Phase II Rule, stated that

"reducing intake flow by installing flow reduction technologies will result in a similarly high reduction of impinged and entrained organisms." (Federal Register Vol. 69, No. 131, pg. 41612). EPRI did find that a reduction in flow through an existing intake will also result in a reduction in velocity; and there is a clear relationship between a reduction in velocity and a reduction in impingement. While dry or closed-cycle cooling achieves the greatest reduction in flow, there are two other methods used to reduce flow. Both of these methods involve reducing the flow during non-peak generation times. The first technique is to reduce the number of cooling water pumps in operation and the second is to install variable speed drives on the pump motors that can achieve a greater level of control for flow reduction. Unfortunately, nuclear facilities are baseloaded and there is a direct relationship between cooling water flow and generation capacity. As a result there is little opportunity to make any significant reduction in flow at nuclear plants using these methods.

7.2.7 Behavioral Devices

Behavioral devices, such as use of sound or light, tend to be effective only on a species-specific and seasonal basis. In general, sound is most effective for species such as alosids that have an air bladder. Both the James R. Fitzpatrick and Point Beach Nuclear Plants have used acoustic fish deterrents (AFDs) effectively to reduce the impingement of alewife that was the dominant impinged fish species. The Fitzpatrick AFD was demonstrated to reduce alewife impingement in excess of 90%.

7.2.8 Change in Intake Location

Although very site-specific, there are instances where relocation of the intake structures has achieved significant reduction in impingement. One is in the Great Lakes, where fish tend to be most abundant along the shoreline and in near shore areas. Locating the entrance to the intake offshore in colder deeper water and/or using an offshore velocity cap can result in reduced fish impingement. This is also true on the West Coast where the water depth drops off quickly due to the relatively short distance to the continental shelf. Withdrawing colder deeper water can also reduce the amount of cooling water needed and improve unit efficiency.

7.3 Alternative Fish Protection Technologies to Reduce Entrainment Mortality

Due to the small size and more fragile nature of entrainable life stages, and the amount of water required for once-through cooling, reducing entrainment mortality is significantly more challenging than reducing impingement mortality. However, there are a number of options that may be practical to reduce entrainment losses based on the same factors discussed for impingement mortality reduction. The categories of options are similar to those listed for impingement mortality reduction; however, the options are more limited since most entrainable life stages tend to behave as passive water particles. As a result, behavioral devices and diversion systems which rely on a fish behavior response

are ineffective. In general, flow reduction is not considered practical for nuclear power plants, other than use of closed-cycle cooling, since nuclear facilities are baseloaded. A short summary of the major categories of potential options is provided below.

7.3.1 Exclusion Devices

Exclusion technologies for entrainment reduction include narrow-slot wedgewire screens and the aquatic filter barrier (AFB). Narrow slot wedgewire screens are the same as described under Section 7.2.1, however, the slot width is reduced to a range from 0.5 mm to 2.0 mm depending on the entrainable life stages in the vicinity of the intake. The AFB is essentially a sophisticated barrier net that incorporates an airblast cleaning system to control biofouling and remove debris that accumulates on the barrier. These technologies work by using a low through-slot or mesh velocity that is equal to or less than 0.5 fps. The result is that a significant amount of surface area is required to achieve the low velocity and that may be problematic depending on the site. Currently, there are no nuclear generating stations that use narrow slot wedgewire screens, and there has only been a single fossil facility in the U.S. (i.e., Lovett Station which is now retired) that has used an AFB. [Ref. 31] In general the AFB is not considered practical for facilities located on the open ocean, in areas with significant waterborne debris, or in areas where it could affect water navigation. Opportunities for use at existing once-through cooled nuclear stations is expected to be very limited due to the higher flow rates and the amount of cloth area that would be needed.

Narrow-slot wedgewire screens, due to the variety of deployment options (i.e. deployment offshore or from a bulkhead and a variety of module sizes) have greater potential for use. Generally deployment for facilities on open oceans would be extremely difficult due to the high biofouling rate in marine environments and the limited capabilities of the airblast system to control that fouling. Adequate depth is also a concern for this option. EPRI evaluated the practicality of narrow-slot wedge-wire screens for the Monticello Nuclear Generating Plant and it was estimated that some 224 two-foot diameter screen modules would be required due to the shallow depth of the Mississippi River as it flows by this facility.

7.3.2 Fish Collection and Transfer Technologies

Fish collection and transfer technologies are the same as described for impingement mortality reduction. Ristroph-modified band screens, Passavant-Geiger Rotary, Hydrolox molded polymer screen, and Beaudry WIP vacuum screen all are manufactured in a fine-mesh screen version. Generally, most are designed to fit into existing screen wells and tend to be the lowest cost fish protection technology to reduce entrainment. However, as discussed for impingement, performance varies greatly depending on the species of concern. EPRI laboratory research has found that survival rates for the earliest entrainable life stages (i.e., larvae less than 12 mm tail length) is very low as these life stages have not yet developed scales and musculature to survive the impingement

process. Additionally, early life stages of more fragile species such as shad, herring and bay anchovy have been found to generally have poor impingement survival rates. Recreational species tend to be hardy and EPRI studies documented relatively high survival rates for these species.

The MIS and AquaSweep design concepts discussed in Section 7.2.2 also have potential for use to reduce entrainment mortality. The MIS is currently designed with 2 mm slot width that is significantly smaller than the 9.5 mm mesh used on conventional traveling screens and would collect and transfer larger entrainable life stages. The flat panel AquaSweep wedgewire screen could be similarly designed with narrower slot wedgewire that would allow entrainables to by-pass the intake.

7.3.4 Change in Intake Location

There are several examples where relocation of the cooling water intakes has achieved significant reduction in entrainment, but this option can be very site-specific. The first is in the Great Lakes. For many of the lakes, the major spawning tends to be along the shoreline such that locating the intake structure offshore in deeper water results in a significant reduction in the number of entrained organisms. A second example is depth. A new fossil facility (proposed Bonnet Carre Generating Station) was approved under CWA Section 316(b) Phase I, Track 2 (allows use of once-through cooling) after demonstrating the equivalent of a 90% reduction in entrainment could be achieved by withdrawing cooling water from the bottom of the lower Mississippi River due to the significantly lower densities of entrainable life stages at those depths compared to shoreline densities at the surface. [Ref. 32]

7.4 Summary of the Potential Use of Alternative Fish Protection Technologies and Operational Measures for Nuclear Power Plants

Approximately one third of the 39 existing once-through cooled nuclear generating stations have already installed fish protection technologies and operational measures, or have instituted environmental mitigation measures to offset impingement and/or entrainment losses. There are additional fish protection technologies that can potentially be deployed to further reduce impingement mortality, and a more limited set of options that can potentially be deployed to further reduce entrainment mortality. These alternate operational measures and technologies may reduce the potential for adverse environmental impact without increasing consumptive water use, and without the other detriments associated with retrofitting closed-cycle cooling. Flow reductions, other than use of closed-cycle cooling, are generally not considered practical for nuclear facilities due to their continuous baseloaded operation.

Section 8: Summary and Conclusions

Since the 1980s, most new plants have been designed with closed-cycle cooling. Three regulatory and/or policy drivers have affected this:

- 1. Concern for potential impacts of the heated water discharged back to the source waterbody,
- 2. Impacts of the plants' cooling water intake structures on fish and aquatic organisms,
- 3. Freshwater availability, especially in arid regions of the U.S. or regions without large waterbodies from which to withdraw cooling water.

The Clean Water Act regulates the first two of these drivers and has been a major factor in the shift toward closed-cycle cooling over the last two to three decades. In contrast, no federal regulations serve as a "driver" to manage the consumptive use of water. As a result, state, regional and commercial interests are most active in this area. As discussed in this report, managing competing stakeholder interests for limited water resources is becoming increasingly important, and efforts to coordinate among federal and state authorities can be difficult.

The purpose of this report was to examine all three of these drivers together to determine options for meeting these often competing goals. This report has addressed the technological design details and various factors considered in selecting once-through cooling vs. closed-cycle cooling technology systems for a given site, with particular emphasis on nuclear plants. Choices of preferred technologies are highly site-specific, which has led to a wide range of technical alternatives, including mechanical cooling towers, hyperbolic cooling towers, cooling ponds, dry cooling technologies, hybrid cooling systems that use both wet and dry cooling, as well as a wide range of intake technologies and operational measures to minimize potential impacts to aquatic life.

In general, closed-cycle cooling performs better in addressing drivers 1 and 2 above, and can address cooling needs for plants with insufficient water availability for once-through cooling (driver 3), but has higher consumptive water usage. Once-through cooling generally performs in reverse of these – worse in addressing drivers 1 and 2, but better in addressing driver 3. The end result, balancing these potential environmental impacts, is highly dependent on the specific features and environmental needs of a particular site and its source water

body. At each site, these three drivers may vary in importance depending upon the makeup of the local ecology.

8.1 Consumptive Use of Water

The consumptive use of water is an important environmental issue, with major strategic implications to several regions of the U.S. Water shortages and water use conflicts are increasingly becoming major concerns in some parts of the U.S. Increased demand by multiple water users is inevitable, and shortages are likely to become more acute in coming decades. Competition over limited fresh water resources may become increasingly intense in many regions of the U.S.

In general, currently available information indicates recirculating cooling technologies consume at least twice as much water as once-through cooling technologies. As such, converting existing once-through cooling facilities to closed-cycle cooling has the potential to adversely affect water availability in some regions of the U.S.

As discussed in Chapters 2 and 3, many fossil and nuclear units were designed with closed cycle cooling to address thermal issues, especially ones sited on smaller water bodies; and a number of once-through-cooled fossil facilities have been required to retrofit with closed-cycle cooling to address these same thermal issues. Managing consumptive water use at such sites during high temperature and/or drought conditions is particularly challenging. Plant shutdowns or derates have proven necessary when plants approach thermal limits or when source water body water levels drop too low to meet circulating water pump net suction head requirements. Long term solutions for such sites may include:

- Helper towers, as discussed in Section 2.3.3.
- Reservoir enhancements to increase water storage capacity (e.g., dredging, dam height increases)
- Additional water storage in nearby storage ponds or reservoirs, topped off during winter or spring and depleted as needed during summer months
- Augmenting wet closed-cycle cooling with additional dry cooling capacity for use in drought conditions (see Section 2.3.5 for this option at North Anna's planned new Unit 3).

8.2 Tying Together the Trade-offs into Three Categories

The following summary is assembled in three categories: current facilities, new plants on existing sites, and new plants on new sites. The tradeoffs of closed-cycle cooling and once-through cooling that have been presented earlier in this report are factored into each of these three categories, in order to present the practical implications.

Given the general trend toward closed-cycle cooling based on drivers 1 and 2, the following discussion highlights instances where the relative importance of driver

3 at a particular site might favor once-through cooling in a balanced assessment of options.

8.2.1 Existing Facilities

As discussed in Chapter 1, most thermoelectric generating facilities used once-through cooling prior to the 1970s. Regulatory initiatives, most notably the CWA, resulted in increased use of closed-cycle cooling from the 1970s through the 1980s. About 60% of currently operating nuclear plants in the U.S. use once-through cooling and 40% use closed-cycle cooling.

The issue for existing facilities relative to selecting once-through vs. closed-cycle cooling is a central part of the proposed 316(b) rule: should existing once-through facilities be converted to closed-cycle cooling? Chapter 2 described the proposed rule and options being considered by EPA. Chapter 6 summarized the reports prepared by EPRI to address the complex environmental and economic issues involved in this question, and the costs and benefits of retrofitting. EPRI's analysis showed that on a national basis, the annualized cost of retrofitting the nuclear facilities is about 800 times greater than the annual environmental benefits of retrofitting. While this cost-benefit estimate comparison does not include an economic estimate of non-use societal benefits, it also does not include the willingness to pay to avoid the localized impacts associated with closed-cycle cooling discussed in Section 4.4.

8.2.2 New Plants on Existing Sites

EPA's proposed rule imposes requirements for new plants on existing sites that are substantially similar to the EPA's requirements for new plants as set forth its 2001 Phase I rule.

As discussed in Chapter 2, Option 1 in the proposed rule allows for flexibility on the part of the permitting authority to consider a number of site-specific factors that might influence a BTA decision, especially in the case of entrainment. For example, a new plant on an existing site may be able to use once-through cooling if it can demonstrate equivalent fish protection to closed-cycle cooling. However, other factors that the permitting authority must consider have nothing to do with fish protection. For example, if imposing closed-cycle cooling on an existing plant would create serious problems with the consumptive use of water at a particular site, then the permitting authority is allowed to consider that situation in making the BTA decision (e.g., allowing once-through cooling, with other BTA protections as appropriate to that site, to be designated as that site's BTA), for the existing unit. However, in that instance, the permitting authority is not allowed to come to that same conclusion for a new plant built on that same site, because the once-through cooling option is only available for that site via a fish protection criterion unrelated to consumptive use. Other limiting factors unrelated to fish protection, such as particulate emissions in excess of Clean Air Act requirements, could prevent closed-cycle cooling from being considered as BTA for an existing plant, but the permitting authority is not allowed to come to that same conclusion for a new plant on that same site – one that could create the same particulate emissions if closed-cycle cooling is imposed on that new plant. Land use is another example of a limiting factor relevant to this decision, because of the additional land requirements associated with installing cooling towers.

As discussed in Section 3.3.2, (note specifically the quote from EPA's proposed rule), the 2001 Phase I rule envisioned that new units on existing sites would be subject to existing facility regulations for that site. However, the proposed rule for existing facilities reversed this, imposing Phase I regulations on new units on existing sites. The implications of this change are unclear for facilities that lack adequate space for closed-cycle cooling or that may be precluded from use of closed-cycle cooling due to permitting issues. Further, the proposed rule's approach to new plants on existing sites is based on a rationale developed from fossil plant trends. Fossil data analyzed in 2001 for the Phase I rule suggested that only 24% of new coal capacity and only 12% of new combined cycle capacity would be constructed on existing sites. However, as discussed in Chapter 3, the U.S. nuclear industry will rely extensively on existing plant sites as the home for additional nuclear reactor capacity. Roughly 60% to 80% of future nuclear capacity is anticipated to be constructed on existing nuclear plant sites, based on current trends. Thus, the proposed Phase II rule may have the effect of limiting the number of new nuclear units that could be built on existing sites.

8.2.3 New Plants on New Sites

The basis for selecting closed-cycle cooling vs. once-through cooling for new plants on new sites is established in EPA's 2001 Phase I rule. As discussed in Chapter 2, the 2001 rule effectively establishes closed-cycle cooling as BTA for new plants, with a "Track 2" or "demonstration track" option that allows for an alternate technology or a combination of technologies and operating methods that reduce adverse environmental impact to a level comparable to closed-cycle cooling. As discussed in Chapter 3, no construction permits for nuclear plants have been issued for nuclear plants using once-through cooling since the late 1970s. No nuclear plants have exercised the Track 2 option, including all new plants in the planning and licensing process.

Given growing concerns for future water use conflicts, there may be potential situations or scenarios where the Track 2 option might be exercised for new nuclear units. If so, the following research and data needs could better enable the exercise of Track 2:

New plant sites where consumptive water use is a priority consideration. There are regions of the U.S. where anticipated load growth will demand additional generating capacity and where available water rights are fully allocated and/or there is strong competition for remaining water resources. A good example of this is in the upper Great Lakes region. Planners in this region might consider the option of once-through cooling for new capacity to help address regional issues with declining lake levels, using additional BTA options such as best screen technology and/or deep water intakes as necessary. Research that could reduce the risks, time delays and uncertainties associated with the Track 2 option would benefit those planners.

New plant sites in Ocean/Estuary/Tidal River (O/E/TR) regions. This is a more difficult situation for the possible use of once-through cooling, because these O/E/TR regions typically have more stressed fisheries, and because consumptive use of fresh water is not an issue in these regions. However, new plant siting in these regions has an important indirect impact on the consumptive use of water, because these plants can benefit from the efficiency of once-through cooling without as large an impact on freshwater consumption, theoretically reducing the number of new plants built on freshwater sites.

As discussed in Chapter 5, the consumptive use of water has major strategic implications to the U.S. and globally. Water shortages and water use conflicts are already major concerns in some parts of the U.S. Increased demand by multiple water users is anticipated, and shortages are expected to become increasingly acute in coming decades.

As discussed in Chapter 3, the U.S. relies much more on fresh water for nuclear plant cooling and less on saline waterbodies (i.e., oceans, estuaries, and tidal rivers) than other nations, by over a factor of two. The data also show that the U.S. relies much more on closed-cycle cooling and much less on once-through cooling for its nuclear plants than other nations, by a factor of about 1.7. Countries with geographic access to oceans preferentially site thermoelectric plants at O/E/TR sites, if available, for thermoelectric plant cooling, in large part to take advantage of the cooler water for efficiency reasons, but also to preserve limited and valuable inland fresh water resources for other water users (such as municipal water supply and agriculture).

As discussed in Chapter 6, not all nuclear units in O/E/TR environments have significant issues with impingement and entrainment: thirteen units at O/E/TR sites have been judged to have "small" environmental impacts. Twelve of these 13 reactors use once-through cooling on O/E/TR sites. In summary, NRC has determined, based on NEPA criteria, that over 60% of reactors on O/E/TR sites that have been evaluated to date for license renewal exhibit "small" environmental impacts.

The option of using once-through cooling for new plants at O/E/TR sites, as a siting strategy to reduce consumptive use of fresh water, is available through Track 2 of the Phase I rule. However, plant performance, reliability and environmental complications as well as the added costs of using cooling towers in saline environments serve as strong disincentives to power plant siting in these regions. Significant technical and environmental analysis would be necessary to implement selective use of once-through cooling in these environments. Selective use of once-through cooling using Track 2 is most feasible in O/E/TR regions where environmental impacts could be smaller (e.g., areas with low migratory fish populations, sites conducive to deep water intakes, sites in industrial areas or navigation channels). This siting strategy could reduce new plant siting on fresh water bodies.

• New plant sites in other regions with limited fresh water resources. Reliable access to ample supplies of cooling water to current and future power plants

is very important to utilities. A broad range of technical solutions have been developed, many with highly site-specific applicability. Among these are dry cooling technologies and non-traditional water resources, such as:

- Reclaimed or reprocessed water (e.g., municipal waste water treatment effluent)
- Saline aquifers and collector wells (poor quality groundwater)
- "Produced" water from energy production (oil and gas wells, mine pool water in abandoned coal mines, etc.)
- Excess run-off from irrigation
- Storm water

These options are increasingly being considered for new plants. For example, new reactors planned for the Turkey Point site in Florida will use Miami/Dade County municipal effluent for cooling water, eliminating the need to use fresh water. This choice has the added advantage of helping the State of Florida address salt water intrusion into inland regions of the state, being driven by increased withdrawal of fresh surface water and groundwater by public, industrial and agricultural users. Many of the other non-traditional options listed above are being considered in the planning for new reactor deployment in the U.S.

Other future strategies that can improve reliable access to ample supplies of cooling water include increased use of cooling ponds, makeup water ponds for drought mitigation, and reservoir preservation and expansion. The feasibility of these strategies is highly site-specific and not generally available for many new plant siting options. However, where applicable, they can reduce water consumption (cooling ponds consume less water than cooling towers), and provide greater assurance of reliable cooling water supplies during drought conditions.

8.3 Key Conclusions

Water resources are critical to power generation. 98% of current electricity generation requires water for cooling (fossil and nuclear power plants) or for motive force (hydroelectric plants). Adequate water resources are becoming problematic in many regions of the U.S., with competition among water users expected to grow – to critical levels in some regions of the U.S. Although utilities can reasonably predict regional power demands and associated cooling water needs 10-20 years into the future, it is very difficult for any plant owner to predict today what the competing demands for water will be at a specific site for the full life of that plant, especially nuclear plants with an anticipated lifespan in the range of 60 to 80 years.

Nuclear energy can help fill the need for new generating capacity to help preserve a diverse future supply of electricity. However, nuclear energy is faced with three potential issues resulting from the CWA:

- Increased concern over thermal discharges, especially in water constrained areas or during summer months with high discharge temperatures or under possible drought conditions.
- Potential 316(b) requirements to retrofit existing once-through cooled facilities with closed-cycle cooling, if designated as BTA. The costs associated with retrofitting existing once-through-cooled nuclear plants were estimated to be about \$32 billion (and cost over \$100 billion to retrofit both nuclear and fossil plants) a cost that would be passed on to consumers in the form of higher energy prices. For new plants, the CWA limits options for possible use of once-through cooling.
- Based on available information, closed cycle cooling consumes approximately twice as much water as once-through cooling. This introduces the potential for increased competition among freshwater-users on a regional basis for new and existing generating facilities. Closed-cycle cooling could also create sitespecific issues relative to adequate water supplies for plants on cooling ponds or small reservoirs.

Siting of new generation capacity will become increasingly challenging in the decades ahead, as cooling water resources become more constrained, and as available land for power plant siting becomes more limited. This will place increased emphasis on the optimum utilization of existing fossil and nuclear sites, with their established transmission access, water access, infrastructure for fuel storage and handling, etc. For nuclear plants, existing sites provide the additional advantages of assured safety and security capabilities (e.g., well-characterized seismic safety performance).

There are alternative technologies to address impingement and entrainment issues that could be sufficient to allow use of once-through cooling. Dry cooling is especially problematic for nuclear power plants, but hybrid cooling may need to be considered in certain water-challenged regions of the U.S. This approach, although very costly, would minimize the safety and licensing consequences of dry cooling.

Section 9: References

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Appendix A: U.S. Nuclear Reactor Listing, by Unit and by USGS Water Resource Region

Reactor	Operator / Licensee	State	Cooling Water Source	Cooling System Type	Condenser Flow Rate (1000 gpm) (NUREG- 1437)	RX Type / NSSS Supplier	Summer Capacity, MWe (NUREG- 1350)	Thermal Output MWth Original / Uprated	Operating License Issued / Expires (NUREG- 1350) [or COL subm. date]
	ON: 5 OPERATING REACTOR U			la = .		I			
Seabrook Pilgrim-1	FPL Group Entergy Nuclear	NH MA	Atlantic Ocean Cape Cod Bay/Atlantic Ocean	Once-Through Once-Through		PWR-West. BWR-GE	1244 685	3411 / 3648 1998 /	1990 / 2030 # 1972 / 2012 #
Millstone-2	Dominion Generation	CT	Niantic Bay/L.I. Sound/Atlantic	Once-Through		PWR-CE	822	2530 / 2700	1972 / 2012 #
Millstone-3	Dominion Generation	СТ	Niantic Bay/L.I. Sound/Atlantic	Once-Through		PWR-West.	1155	3411/	1986 / 2045
Vermont Yankee	Entergy Nuclear	VT	Vernon Pool on Connecticut River	O-T plus towers (mechanical)	366	BWR-GE	620	1593 / 1912	1973 / 2032
			AT ELEVEN SITES PLUS 3 NEW UNITS P					•	
Indian Point-2	Entergy Nuclear	NY NY	Hudson River Hudson River	Once Through		PWR-West. PWR-West.	1020 1025	2758 / 3216 3025 / 3067	1973 / 2013 # 1976 / 2015 #
Indian Point-3 Susquehanna-1	Entergy Nuclear PPL Susquehanna LLC	PA	Susquehanna River	Once Through Tower (1; natural draft)		BWR-GE	1135	3025 / 3067	1976 / 2015 #
Susquehanna-2	PPL Susquehanna LLC	PA	Susquehanna River	Tower (1; natural draft)		BWR-GE	1140	3293 / 3441	1983 / 2044
Bell Bend (one unit)	PPL Susquehanna LLC	PA	Susquehanna River	Towers (2; natural draft)		EPR	~1600		COL: 10/2008
Limerick-1	Exelon Generation	PA	Schuylkill River	Tower (1; natural draft)		BWR-GE	1134	3293 / 3458	1984 / 2024 #
Limerick-2	Exelon Generation	PA	Schuylkill River	Tower (1; natural draft)		BWR-GE	1134	3293 / 3458	1989 / 2029 #
Peach Bottom-2 Peach Bottom-3	Exelon Generation Exelon Generation	PA PA	Conowingo Pond on Susquehanna Conowingo Pond on Susquehanna	O-T (mech. towers available) O-T (mech. towers available)		BWR-GE BWR-GE	1112 1112	3293 / 3514 3293 / 3514	1973 / 2033 1974 / 2034
TMI-1	Exelon Generation	PA	Susquehanna River	Towers (2; natural draft)		PWR-B&W	786	2535 / 2568	1974 / 2034
Oyster Creek	Exelon Generation	NJ	Barnegat Bay	Once Through		BWR-GE	619	1930/	1969 / 2029
Salem-1	PSEG Nuclear LLC	NJ	Delaware River	Once Through	1100	PWR-West.	1174	3411 / 3459	1976 / 2036
Salem-2	PSEG Nuclear LLC	NJ	Delaware River	Once Through		PWR-West.	1130	3411 / 3459	1981 / 2040
Hope Creek	PSEG Nuclear LLC	NJ	Delaware River	Tower (1; natural draft)	552	BWR-GE	1061	3293 / 3393	1986 / 2046
(new unit @ Salem/H.C.	•	NJ MD	Chesaneake Bay	Once Through	1200	<i>TBD</i> PWR-CE	873	ESP under rev. 2560 / 2700	ESP: 5/2010 1974 / 2034
Calvert Cliffs-1 Calvert Cliffs-2	Constellation Energy Constellation Energy	MD	Chesapeake Bay Chesapeake Bay	Once Through Once Through		PWR-CE PWR-CE	862	2560 / 2700 2560 / 2700	1974 / 2034
Calvert Cliffs-3	UNISTAR/Constellation	MD	Chesapeake Bay	1 mech tower w/plume abatemen		EPR	~1600		COL: 3/2008
North Anna-1	Dominion Generation	VA	Lake Anna (fed by N. Anna River)	Once Through	T T	PWR-West.	924	2775 / 2893	1978 / 2038
North Anna-2	Dominion Generation	VA	Lake Anna (fed by N. Anna River)	Once Through	940	PWR-West.	910	2775 / 2893	1980 / 2040
North Anna-3	Dominion Generation	VA	Lake Anna (fed by N. Anna River)	Hybrid (wet/dry combo) tower		US-APWR	~1700	ESP issued	COL: 11/2007
Surry-1	Dominion Generation	VA	James River	Once Through		PWR-West.	799 799	2441 / 2546	1972 / 2032
Surry-2 3. SOUTH ATI ANTIC-GU	Dominion Generation	VA FACTO	James River R UNITS AT 13 SITES - PLUS 12 NEW UNI	Once Through TS PLANNED (Note: 15 total sites in		PWR-West.		2441 / 2546	1973 / 2033 & Southern sites)
McGuire-1	Duke Energy	NC	Lake Norman on Catawba River	Once Through		PWR-West.	1100	3411/	1981 / 2041
McGuire-2	Duke Energy	NC	Lake Norman on Catawba River	Once Through		PWR-West.	1100	3411/	1983 / 2043
Catawba-1	Duke Energy	SC	Lake Wylie on Catawba River	Towers (mechanical)	660	PWR-West.	1129	3411/	1985 / 2043
Catawba-2	Duke Energy	SC	Lake Wylie on Catawba River	Towers (mechanical)		PWR-West.	1129	3411/	1986 / 2043
Oconee-1	Duke Energy	SC SC	Lake Keowee (fed by Keowee & Little Rivers	ū		PWR-B&W PWR-B&W	846	2568 /	1973 / 2033
Oconee-2 Oconee-3	Duke Energy Duke Energy	SC	Lake Keowee (fed by Keowee & Little Rivers Lake Keowee (fed by Keowee & Little Rivers			PWR-B&W	846 846	2568 / 2568 /	1973 / 2033 1974 / 2034
William S. Lee-1	Duke Energy	SC	Broad River	Towers (3; mechanical)	000	AP1000	~1150	23007	COL: 12/2007
William S. Lee-2	Duke Energy	SC	Broad River	Towers (3; mechanical)		AP1000	~1150		COL: 12/2007
(Davie County)	Duke Energy	NC		TBD		TBD			TBD
(Oconee County)	Duke Energy	SC		TBD		TBD			TBD
Harris-1	Progress Energy	NC	Lake Harris (fed by Buckhorn Creek)	Tower (1; natural draft)	483	PWR-West.	900	2775 / 2900	1987 / 2046
Harris-2 Harris-3	Progress Energy Progress Energy	NC NC	Lake Harris (will raise level ~20 ft.) Lake Harris (will raise level ~20 ft.)	Towers (1; natural draft) Towers (1; natural draft)		AP1000 AP1000	~1150 ~1150		COL: 2/2008 COL: 2/2008
Robinson-2	Progress Energy	SC	Lake Robinson on Black Creek	Once Through	482	PWR-West.	710	2200 / 2339	1970 / 2030
Brunswick-1	Progress Energy	NC	Cape Fear River	Once Through		BWR-GE	938	2436 / 2923	1976 / 2036
Brunswick-2	Progress Energy	NC	Cape Fear River	Once Through	675	BWR-GE	900	2436 / 2923	1974 / 2034
Summer-1	South Carolina E&G	SC	Lake Monticello (drains to Broad River)	Once Through	485	PWR-West.	966	2775 / 2900	1982 / 2042
Summer-2	South Carolina E&G	SC	Lake Monticello (drains to Broad River)	Towers (mechanical)		AP1000	~1150		e sked. early 2012
Summer-3 Vogtle-1	South Carolina E&G Southern Nuclear	<i>SC</i> GA	Lake Monticello (drains to Broad River) Savannah River	Towers (mechanical) Tower (1; natural draft)	510	AP1000 PWR-West.	~1150 1152	3411 / 3565	2 sked. early 2012 1987 / 2047
Vogtle-2	Southern Nuclear	GA	Savannah River	Tower (1; natural draft)		PWR-West.	1149	3411 / 3565	1989 / 2049
Vogtle-3	Southern Nuclear	GA	Savannah River	Tower (1; natural draft)	310	AP1000	~1150		e sked. early 2012
Vogtle-4	Southern Nuclear	GA	Savannah River	Tower (1; natural draft)		AP1000	~1150		sked. early 2012
Hatch-1	Southern Nuclear	GA	Altamaha River	Towers (4; mechanical)		BWR-GE	876	2436 / 2763	1974 / 2034
Hatch-2	Southern Nuclear	GA	Altamaha River	Towers (4; mechanical)		BWR-GE	883	2436 / 2763	1978 / 2038
Farley-1 Farley-2	Southern Nuclear Southern Nuclear	AL AL	Chattahoochee River Chattahoochee River	Towers (3; mechanical) Towers (3; mechanical)		PWR-West. PWR-West.	851 860	2652 / 2775 2652 / 2775	1977 / 2037 1981 / 2041
(TBD)	Southern Nuclear	TBD	TBD		033	TBD	500	2032 2113	COL: plan 2011
Crystal River-3	Progress Energy	FL	Gulf of Mexico	Once Through	680	PWR-B&W	838	2544 /	1977 / 2016 #
Levy County-1	Progress Energy	FL	Cross Florida Barge Canal (to Gulf)	Towers (mechanical)		AP1000	~1150		COL: 7/2008
Levy County-2	Progress Energy	FL	Cross Florida Barge Canal (to Gulf)	Towers (mechanical)		AP1000	~1150		COL: 7/2008
			Atlantic Ocean	Once Through		PWR-CE	839	2560 / 2700	1976 / 2036
St. Lucie-1	Florida Power & Light	FL	Atlantia Octor			PWR-CE	839	2560 / 2700	1983 / 2043
St. Lucie-2	Florida Power & Light	FL	Atlantic Ocean	Once Through					1972 / 2022
St. Lucie-2 Turkey Point-3			Atlantic Ocean closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay)	Once Through	624	PWR-West.	693 693	2200 / 2300 2200 / 2300	1972 / 2032 1973 / 2033
St. Lucie-2	Florida Power & Light Florida Power & Light	FL FL	closed canal system (off Biscayne Bay)	Once Through Once Through	624	PWR-West.	693	2200 / 2300	1972 / 2032 1973 / 2033 <i>COL: 6/2009</i>
St. Lucie-2 Turkey Point-3 Turkey Point-4	Florida Power & Light Florida Power & Light Florida Power & Light	FL FL FL	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay)	Once Through Once Through	624	PWR-West. PWR-West.	693 693	2200 / 2300	1973 / 2033
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION +	Florida Power & Light + OHIO REGION: 8 OPERATING	FL FL FL FL REACT	closed canal system (off Biscayne Bay), closed canal system (off Biscayne Bay), Municipal effluent from Miami/Dade + (Same) OR UNITS AT FOUR SITES - P.U.5 2 NEV	Once Through Once Through	624 624 e: 4 total sit	PWR-West. PWR-West. AP1000 AP1000 es; doesn't i	693 693 ~1150 ~1150 ndude Bel	2200 / 2300 2200 / 2300 lefonte, Clinc	1973 / 2033 COL: 6/2009 COL: 6/2009 h River, Piketon)
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION + Beaver Valley-1	Florida Power & Light + OHIO REGION: 8 OPERATING FirstEnergy Nuclear	FL FL FL FL FL REACT	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay) Municipal effluent from Miami/Dade + (Same) OR UNITS AT FOUR SITES - PLUS 2 NEV Ohio River	Once Through Once Through Saltwater from collector wells Towers (mechanical; both units) UNITS COMPLETING CONST. (No Tower (1; natural draft)	624 624 e: 4 total sit 480	PWR-West. PWR-West. AP1000 AP1000 es; doesn't I	693 693 ~1150 ~1150 nclude Bel 849	2200 / 2300 2200 / 2300 lefonte, Clino 2652 / 2900	1973 / 2033 COL: 6/2009 COL: 6/2009 River, Piketon) 1976 / 2036
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION + Beaver Valley-1 Beaver Valley-2	Florida Power & Light + OHIO REGION: 8 OPERATING FirstEnergy Nuclear FirstEnergy Nuclear	FL FL FL FL FL REACT PA	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay) Municipal effluent from Miami/Dade + (Same) TOR UNITS AT FOUR SITES - PLUS 2 NEV Ohio River Ohio River	Once Through Once Through Saltwater from collector wells Towers (mechanical; both units) UNITS COMPLETING CONST. (No Tower (1; natural draft) Tower (1; natural draft)	624 624 e: 4 total sit 480 480	PWR-West. PWR-West. AP1000 AP1000 es; doesn'ti PWR-West. PWR-West.	693 693 ~1150 ~1150 ndude Bel 849 832	2200 / 2300 2200 / 2300 2200 / 2300 lefante, Clina 2652 / 2900 2652 / 2900	1973 / 2033 COL: 6/2009 COL: 6/2009 River, Piketon) 1976 / 2036 1987 / 2047
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION - Beaver Valley-1 Beaver Valley-2 Browns Ferry-1	Florida Power & Light + OHIO REGION: 8 OPERATING FirstEnergy Nuclear FirstEnergy Nuclear Tennessee Valley Authority	FL FL FL FL FL REACT PA PA AL	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay) Municipal effluent from Miami/Dade + (Same) TOR UNITS AT FOUR SITES — PLUS 2 NEV Ohio River Ohio River Tennessee River	Once Through Once Through Saltwater from collector wells Towers (mechanical; both units) UNITS COMPLETING CONST. (No Tower (1; natural draft) Tower (1; natural draft) O-T + Helper Towers (mechanical)	624 624 e: 4 total sit 480 480 630	PWR-West. PWR-West. AP1000 AP1000 es; doesn't PWR-West. PWR-West. BWR-GE	693 693 ~1150 ~1150 nclude Bel 849 832 1065	2200 / 2300 2200 / 2300 2200 / 2300 lefonte, Clino 2652 / 2900 2652 / 2900 3293 /	1973 / 2033 COL: 6/2009 COL: 6/2009 Niver, Piketon) 1976 / 2036 1987 / 2047 1973 / 2033
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION + Beaver Valley-1 Beaver Valley-2	Florida Power & Light + OHIO REGION: 8 OPERATING FirstEnergy Nuclear FirstEnergy Nuclear	FL FL FL FL FL FL A REACT PA AL AL	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay) Municipal effluent from Miami/Dade + (Same) TOR UNITS AT FOUR SITES - PLUS 2 NEV Ohio River Ohio River	Once Through Once Through Saltwater from collector wells Towers (mechanical; both units) UNITS COMPLETING CONST. (No Tower (1; natural draft) Tower (1; natural draft)	e: 4 total sit 480 480 630	PWR-West. PWR-West. AP1000 AP1000 es; doesn'ti PWR-West. PWR-West.	693 693 ~1150 ~1150 ndude Bel 849 832	2200 / 2300 2200 / 2300 2200 / 2300 lefante, Clina 2652 / 2900 2652 / 2900	1973 / 2033 COL: 6/2009 COL: 6/2009 River, Piketon) 1976 / 2036 1987 / 2047
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION -1 Beaver Valley-1 Beaver Valley-2 Browns Ferry-1 Browns Ferry-2	Florida Power & Light OHIO REGION: 8 OPERATING FirstEnergy Nuclear FirstEnergy Nuclear Tennessee Valley Authority Tennessee Valley Authority	FL FL FL FL FL PA PA AL AL	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay) Municipal effluent from Miami/Dade + (Same) TOR UNITS AT FOUR SITES — PLUS 2 NEV Ohio River Ohio River Tennessee River Tennessee River	Once Through Once Through Once Through Saltwater from collector wells Towers (mechanical; both units) UNITS COMPLETING CONST. (No Tower (1; natural draft) Tower (1; natural draft) O-T + Helper Towers (mechanical) O-T + Helper Towers (mechanical)	624 624 624 624 630 630 630 630	PWR-West. PWR-West. AP1000 AP1000 es; doesn'tt PWR-West. PWR-West. BWR-GE BWR-GE	693 693 ~1150 ~1150 nclude Bel 849 832 1065 1118	2200 / 2300 2200 / 2300 2200 / 2300 lefonte, Clino 2652 / 2900 2652 / 2900 3293 / 3293 / 3458	1973 / 2033 COL: 6/2009 COL: 6/2009 Niver, Piketon) 1976 / 2036 1987 / 2047 1973 / 2033 1974 / 2034
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION -1 Beaver Valley-1 Beaver Valley-2 Browns Ferry-1 Browns Ferry-2 Browns Ferry-3 Sequoyah-1 Sequoyah-2	Florida Power & Light	FL FL FL FL FL PA PA AL AL TN	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay) Municipal effluent from Miami/Dade + (Same) OR UNITS AT FOUR SITES PLUS 2 NEW Ohio River Ohio River Tennessee River Tennessee River Tennessee River Chickamauga Lake on Tennessee River Chickamauga Lake on Tennessee River	Once Through Once Through Once Through Saltwater from collector wells Towers (mechanical; both units) UNITS COMPLETING CONST. (No Tower (1; natural draft) Tower (1; natural draft) O-T + Helper Towers (mechanical) O-T + Helper Towers (mechanical) O-T + Helper Tower (natural draft) O-T + Helper Tower (natural draft)	624 624 624 624 630 630 630 630 522 522	PWR-West. PWR-West. AP1000 AP1000 BS, doesn'ts PWR-West. BWR-GE BWR-GE BWR-GE BWR-GE PWR-West. PWR-West.	693 693 ~1150 ~1150 849 832 1065 1118 1114 1150	2200 / 2300 2200 / 2300 2200 / 2300 2600 / 2300 2652 / 2900 3293 / 3293 / 3458 3293 / 3458 3411 / 3455 3411 / 3455	1973 / 2033 COL: 6/2009 COL: 6/2009 Niver, Piketon) 1976 / 2036 1987 / 2047 1973 / 2033 1974 / 2034 1976 / 2036 1980 / 2020 1981 / 2021
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION - Beaver Valley-1 Beaver Valley-2 Browns Ferry-1 Browns Ferry-2 Browns Ferry-3 Sequoyah-1 Sequoyah-2 Watts Bar-1	Florida Power & Light	FL FL FL FL FL FL FL FL TN TN TN	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay) Municipal effluent from Miami/Dade + (Same) OR UNITS AT FOUR SITES PLUS 2 NEV Ohio River Ohio River Tennessee River Tennessee River Tennessee River Chickamauga Lake on Tennessee River Chickamauga Lake on Tennessee River Chickamauga Lake on Tennessee River	Once Through Once Through Saltwater from collector wells Towers (mechanical; both units) Tower (1; natural draft) O-T + Helper Towers (mechanical) O-T + Helper Towers (mechanical) O-T + Helper Towers (mechanical) O-T + Helper Tower (natural draft) O-T + Helper Tower (natural draft) Tower (1; natural draft)	624 624 624 624 630 630 630 630 522 522	PWR-West. PWR-West. AP1000 AP1000 PWR-West. PWR-West. BWR-GE BWR-GE BWR-GE PWR-West. PWR-West. PWR-West.	693 693 ~1150 ~1150 849 832 1065 1118 1114 1150 1127	2200 / 2300 2200 / 2300 2200 / 2300 2652 / 2900 2652 / 2900 3293 / 3293 / 3458 3293 / 3458 3411 / 3455	1973 / 2033 COL: 6/2009 COL: 6/2009 River Piketon) 1976 / 2036 1987 / 2047 1973 / 2033 1974 / 2034 1976 / 2036 1980 / 2020 1981 / 2021 1996 / 2035
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION - Beaver Valley-1 Beaver Valley-2 Browns Ferry-1 Browns Ferry-2 Browns Ferry-3 Sequoyah-1 Sequoyah-2 Watts Bar-1 Watts Bar-2 (complete)	Florida Power & Light OHIO REGION: 8 OPERATING FirstEnergy Nuclear FirstEnergy Nuclear Tennessee Valley Authority	FL FL FL FL FL PA PA AL AL TN TN TN	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay) Municipal effluent from Miami/Dade + (Same) TOR UNITS AT FOUR SITES PLUS 2 MEV Ohio River Ohio River Tennessee River Tennessee River Tennessee River Chickamauga Lake on Tennessee River	Once Through Once Through Saltwater from collector wells Towers (mechanical; both units) Tower (1; natural draft) Tower (1; natural draft) O-T + Helper Towers (mechanical) O-T + Helper Towers (mechanical) O-T + Helper Towers (mechanical) O-T + Helper Tower (natural draft) Tower (1; natural draft) Tower (1; natural draft) Tower (1; natural draft)	624 624 624 480 480 630 630 522 522 410	PWR-West. PWR-West. AP1000 AP1000 Sydoson1 PWR-West. BWR-GE BWR-GE BWR-GE PWR-West. PWR-West. PWR-West.	693 693 ~1150 ~1150 mdude Bel 849 832 1065 1118 1114 1150 1127 1166 ~1180	2200 / 2300 2200 / 2300 2200 / 2300 2600 / 2300 2652 / 2900 3293 / 3293 / 3458 3293 / 3458 3411 / 3455 3411 / 3455 3411 / 3459	1973 / 2033 COL: 6/2009 COL: 6/2009 Niver, Piketon) 1976 / 2036 1987 / 2047 1973 / 2033 1974 / 2034 1976 / 2036 1980 / 2020 1981 / 2021 1996 / 2035 const. restart '07
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION - Beaver Valley-1 Beaver Valley-2 Browns Ferry-1 Browns Ferry-2 Browns Ferry-3 Sequoyah-1 Sequoyah-2 Watts Bar-1 Watts Bar-2 (complete) Bellefonte-1 (complete)	Florida Power & Light	FL FL FL FL FL FL PA PA AL AL TN TN TN AL	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay) Municipal effluent from Miami/Dade + (Same) OR UNITS AT FOUR SITES PLUS 2 NEV Ohio River Ohio River Tennessee River Tennessee River Tennessee River Chickamauga Lake on Tennessee River Guntersville Lake on Tennessee River	Once Through Once Through Saltwater from collector wells Towers (mechanical; both units) TOWER (1; natural draft) Tower (1; natural draft) O-T + Helper Towers (mechanical) O-T + Helper Towers (mechanical) O-T + Helper Tower (natural draft) Tower (1; natural draft)	624 624 624 480 480 630 630 522 522 410	PWR-West. PWR-West. AP1000 AP1000 PWR-West. PWR-West. BWR-GE BWR-GE BWR-GE PWR-West. PWR-West. PWR-West. PWR-West.	693 693 71150 71150 849 832 1065 1118 1114 1150 1127 1166 71180	2200 / 2300 2200 / 2300 2200 / 2300 2600 / 2300 2652 / 2900 3293 / 3293 / 3458 3293 / 3458 3411 / 3455 3411 / 3455 3411 / 3459	1973 / 2033 COL: 6/2009 COL: 6/2009 Niver Piketon 1976 / 2036 1987 / 2047 1973 / 2033 1974 / 2034 1976 / 2036 1980 / 2020 1981 / 2021 1996 / 2035 const. restart '07 K'd by Board, 2011
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION - Beaver Valley-1 Beaver Valley-2 Browns Ferry-1 Browns Ferry-2 Browns Ferry-3 Sequoyah-1 Sequoyah-2 Watts Bar-1 Watts Bar-2 (complete) Bellefonte-1 (complete) Bellefonte-3	Florida Power & Light	FL FL FL FL FL FL PA PA AL AL TN TN TN TN AL AL	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay) Municipal effluent from Miami/Dade + (Same) TOR UNITS AT FOUR SITES PLUS 2 NEV Ohio River Ohio River Tennessee River Tennessee River Tennessee River Chickamauga Lake on Tennessee River Guntersville Lake on Tennessee River Guntersville Lake on Tennessee River	Once Through Once Through Saltwater from collector wells Towers (mechanical; both units) TOWER (1; natural draft) Tower (1; natural draft) O-T + Helper Towers (mechanical) O-T + Helper Towers (mechanical) O-T + Helper Tower (natural draft) O-T + Helper Tower (natural draft) Tower (1; natural draft)	624 624 624 480 480 630 630 630 522 522 410	PWR-West. PWR-West. AP1000 AP1000 PWR-West. PWR-West. BWR-GE BWR-GE BWR-GE PWR-West. PWR-West. PWR-West. PWR-West. PWR-West.	693 693 693 ~1150 ~1150 849 832 1065 1118 1114 1150 1127 1166 ~1180 ~1250 ~1150	2200 / 2300 2200 / 2300 2200 / 2300 2600 / 2300 2652 / 2900 3293 / 3293 / 3458 3293 / 3458 3411 / 3455 3411 / 3455 3411 / 3459	1973 / 2033 COL: 6/2009 COL: 6/2009 Niver Piketon 1976 / 2036 1987 / 2047 1973 / 2033 1974 / 2034 1976 / 2036 1980 / 2020 1981 / 2021 1996 / 2035 const. restart '07 K'd by Board, 2011 COL: 10/2007
St. Lucie-2 Turkey Point-3 Turkey Point-4 Turkey Point-6 Turkey Point-7 4. TENNESSEE REGION - Beaver Valley-1 Beaver Valley-2 Browns Ferry-1 Browns Ferry-2 Browns Ferry-3 Sequoyah-1 Sequoyah-2 Watts Bar-1 Watts Bar-2 (complete) Bellefonte-1 (complete)	Florida Power & Light	FL FL FL FL FL FL PA PA AL AL TN TN TN AL	closed canal system (off Biscayne Bay) closed canal system (off Biscayne Bay) Municipal effluent from Miami/Dade + (Same) OR UNITS AT FOUR SITES PLUS 2 NEV Ohio River Ohio River Tennessee River Tennessee River Tennessee River Chickamauga Lake on Tennessee River Guntersville Lake on Tennessee River	Once Through Once Through Saltwater from collector wells Towers (mechanical; both units) TOWER (1; natural draft) Tower (1; natural draft) O-T + Helper Towers (mechanical) O-T + Helper Towers (mechanical) O-T + Helper Tower (natural draft) Tower (1; natural draft)	624 624 624 480 480 630 630 630 522 522 410	PWR-West. PWR-West. AP1000 AP1000 PWR-West. PWR-West. BWR-GE BWR-GE BWR-GE PWR-West. PWR-West. PWR-West. PWR-West.	693 693 71150 71150 849 832 1065 1118 1114 1150 1127 1166 71180	2200 / 2300 2200 / 2300 2200 / 2300 2600 / 2300 2652 / 2900 3293 / 3293 / 3458 3293 / 3458 3411 / 3455 3411 / 3455 3411 / 3459	1973 / 2033 COL: 6/2009 COL: 6/2009 Niver Piketon 1976 / 2036 1987 / 2047 1973 / 2033 1974 / 2034 1976 / 2036 1980 / 2020 1981 / 2021 1996 / 2035 const. restart '07 K'd by Board, 2011

Appendix B: U.S. Nuclear Reactor Listing, by Site and by Site Situation/Cooling Method

Total number of U.S. Sites: 68 (this number includes all currently operating plant sites, plus planned sites for new plants for which a COL or ESP application has been filed. Therefore, new sites without a COL or ESP application currently on file with NRC are not included below (Amarillo, Green River, Piketon, Clinch River, etc.) This listing includes three "greenfield" sites based on COL applications (Levy, Lee, Bellefonte) and one "greenfield" site based on ESP application (Victoria County) @: Source: NUREG-1437 ACRES@ INTAKE STRUCTURE@ DISCHARGE STRUCTURE @ COMMENTS PLANT SITE COOLING WATER SOURCE JSGS REGION 1075 River bank Susquehanna + Bell Ben Susquehanna River acreage does not include adjacent Bell Bend Site lid-Atlantic Mid-Atlantic 595 From river onsumption issues usquehanna Rive 472 At river bank TMI-1 Mid-Atlantic At shoreline Edge of river 10 ft into river Co-located with Salem 1 & 2 (once-through); Hope Creek uses Hope Creek ∕Iid-Atlantio Delaware River ower. NPDES permits treat Salem & H.C. as separate sites At edge of lake; submerged Cove of lake edge of lake intake for RL system cooling and submerged Lake Wylie on Catawba Rive 391 125 ft from shore take for RN system cooling Harris Lake Harris (on Buckhorn Creek) 10,744 Reservoir on creek To reservoir Lake level to be increased to support units 2&3 3169 At river bank Near shoreline ogtle/ outh Atlantic-Gulf Savannah River 2244 Edge of river outh Atlantic-Gulf Hatch 1850 River to storage pon outh Atlantic-Gulf Chattahoochee River At river bank auxiliary heat loads use once-through cooling arley 501 At river edge At river edge Beaver Valley hio Ohio River auxiliary heat loads use once-through cooling Chickamauga Lake just below Wat At lake bank Holding pond to lake Vatts Bar luring summer months (into Unit 2 cooling tower basin) Bar Dam on Tennessee Rive 1770 Submerged multi-port Intake channel ntersville Lake o<u>n Tennessee</u> 487 Crib 3,300 ft from shore Palisades Great Lakes Lake Michigan 108-ft canal 1120 At edge of lake Lake Erie 50 acre Pond to lake ermi Submerged 3,000 ft of ibmerged 930 ft off shor 954 shore Multiport 2,250 ft off avis Besse reat Lakes Lake Erie iffuser 1,650 ft off shore Lake Erie Great Lakes 1100 shore 500 Shoreline Duane Arnold Canal to shoreline consumption issues Upper Mississippi 1398 On river bank Rock River Discharge to river Upper Mississippi Collector wells Discharge via barge slip Grand Gulf ver Mississippi Wells adjacent to Mississippi Rive 2100 3342 At river bank River Bend Lower Mississippi Mississippi River Into river From river To river Missouri River Callaway 3188 900 feet from shoreline 3 mile pipe, to 175 ft from Pacific Northwest 550 shore Wastewater effluent from Phoenix cost of water is potential issue after lic. renewal (>40 years) alo Verde 4050 35-mile underground pipe Evaporation ponds NOTES: 24 sites in this situation. (22 existing sites, 2 new greenfield sites) Total existing reactors = 32 (+ NMP-2 & ANO-2 = 34) Total new Rx = 11 (includes WB-2 but not suspended COLAs (4)) Note 1: for sites with multiple units, with some units using once-through cooling and some units using closed cooling (towers), the site is listed below in the appropriate once-through category Color code: New Plants are yellow (full row = greenfield, second column only = on existing site; light = not active COL). Plants with 60 year License Res val are green (dark = LR complete; light = EIS only). N #1B SITE USES ONCE THROUGH COOLING ON A MAN-MADE COO closed canal system off Biscayne POND THAT IS EXEMPT FROM CWA 316(b) (Pond Not C ied as "Waters of the U.S.") Intake canal and barge 4000 acre Canal system Units 3/4 used closed canal system; units 6/7 will use Dade 24,000 canal Turkey Point From cooling pond; m/u To cooling pond ooling Lake (off II linois River) Upper Mississippi rom river At lake shore Surface flume raidwood (%) per Mississipp Braidwood Lake (off Kankakee Rive 4457 ooling Res. with m/u fm Colorado nits 3&4 will use main cooling reservoir (MCR), with a to reservoir; m/u to bank o South Texas (%) 12,350 from bank of river exas Gulf River river increased depth of ~2 feet ooling Lake with m/u fm exas Gulf ctoria County Guadalupe River NOTES: 5 sites in this situation (4 existing sites, 1 greenfield site [ESP currently under review]). Note: ones marked (%) are considered cooling ponds by NRC (NUREG-1437). Note 2. nits 1 & 2 use once-through; unit 3 will use a hybrid to Lake shore Via 3400 acre cooling pond 1id-Atlantic orth Anna ake Anna (fed by North Anna Rive 18.643 Acreage includes entire Lake + shoreline 5,000 Edge of lake acreage includes lake plus shoreline Robinson (%) South Atlantic-Gulf Lake Robinson on Black Creek 4.2 mile canal nit 1 uses once-through; units 2 & 3 will use towers. ntake at shorelin Discharge pond to lake ummer (%) uth Atlantic-Gulf make-up from Parr Reservoir 2200 perate in conjunction with pumped storage Canal from Kankakee Rive oling lake to Illinois Rive reage includes 1274 acre cooling lake and spray canal; <u>use</u> oling Lake (off Illinois River pper Mississipp Oresden (%) 14,090 Shoreline of creek Clinton Lake (off Salt Creek) 3-mile flume Upper Mississippi Units 1 & 2 use once-through from Squaw Creek Res.; Units 3 & quaw Creek Reservoir/Lake Shore of reservoir Canal to reservoir Granbury will use towers & get m/u fm Lake Granbury Dissipates heat to Coffey County Cooling lake Cooling lake to embayment Lake on Wolf Cr.; make-up from Jol Wolf Creek (%) IRC LR: I&E Moderate impact NOTES: 7 sites in this situation. Note: ones marked (%) are considered cooling ponds by NRC (NUREG-1437). Note 2.

water back to the main condenser" (ORNL/NUREG/TM-226).								
SITUATION #3: SITE USES ONCE-THROUGH COOLING ON A MULTI-PURPOSE RESERVOIR (in-line with source river)								
Vermont Yankee	New England	Vernon Pool behind Vernon Dam on Connecticut River	125	Edge of river	Aerating structure at edge of river	<u>Uses mech. cooling towers in summer</u> ; avg. consumption <0.1% in tower mode. Max consumption on hottest day is <1.5%		
Peach Bottom	Mid-Atlantic	Conowingo Pond behind Conowingo Dam on Susquehanna River	620	Small intake pond	5,000-ft canal to pond	Mech. cooling towers installed but not used (5 previously used in summer, 3 now retained operable for contingency)		
Browns Ferry	Tennessee	Wheeler Reservoir behind Wheeler Dam on Tennessee River		In small river inlet via skimmer wall & forebay	Diffuser pipes to river	Uses mechanical "helper" towers during warm parts of year. Cannot operate totally in closed cycle mode.		
		Chickamauga Lake on Tennessee		From lake via skimmer wall & forebay	To lake/river via diffuser pipes	Uses natural draft towers as "helpers" during warmer months for large portion of cooling; cannot operate totally in closed		
Sequoyah	Tennessee	River	525			cycle mode. Auxiliary heat loads use once-through cooling		
McGuire	South Atlantic-Gulf	Lake Norman behind Cowans Ford Dam on Catawba River		Submerged and surface at shoreline	2,000-ft canal discharge	capability to mix hypolimnetic water with surface water for cooling		
Oconee	South Atlantic-Gulf	Lake Keowee behind Keowee Dam (fed by Keowee & Little Rivers)	510	'	765 ft deep	hypolimnetic water exclusively used for cooling. Units operate in conjunction with pumped storage.		
		Dardanelle Reservoir on Arkansas		3220-ft canal	520-ft canal			
Arkansas Nuclear One	Arkansas-White-Red	River	1160			Unit 1 uses once-through; unit 2 uses a tower		
NOTES: 7 sites in this situ	uation.							
SITUATION #4: SITE USES	SITUATION #4: SITE USES ONCE THROUGH COOLING ON AN OCEAN OR BAY OPEN TO THE OCEAN							

3 deep structures, 7,000 ft diffuser, 5,500 ft off shore Seabrook New England Atlantic Ocean 896 off shore Edge of bay (protected by Cape Cod Bay/Atlantic Ocean NRC LR: I&E Moderate impact ilgrim lew England 517 breakwater) /ia holding pond Niantic Bay/Long Is. Sound/Atlanti 500 Niantic Bay NRC LR: I&E Moderate impact /lillstone New England 4738 16,000 ft from sh rystal Rive Gulf of Mexico 13,000 ft canal creage includes fossil units uth Atlantic-Gul t. Lucie outh Atlantic-Gulf Atlantic Ocean 1132 1,200 ft off shore 1,200 ft. & 3000 ft. off shore Surface to ocean Diablo Canyon alifornia Pacific Ocean 750 At shore with break wall elocity cap 3,400 ft off 3,800 to 8,500 ft from shor NOTES: 7 sites in this situation

Ovster Creek to bay Forked River from bay Oyster Creek Mid-Atlantic Barnegat Bay 1416 IRC LR: I&F Moderate impact located with Hope Creek (uses a tower). NPDES permits i00 ft into river Edge of river Salem Mid-Atlantic Delaware River 740 treat Salem & Hope Creek as separate sites alvert Cliffs ∕iid-Atlantic Chesapeake Bay 2070 tower with plume abatement 840 1.7-mile canal Mid-Atlantic James River Surry 1200 3-mile canal from river 6-mile canal to Atlantic runswick South Atlantic-Gulf Cape Fear Rive NOTES: 6 sites in this situation.

Canal Canal Uses mechanical "helper" towers during warm parts of year. Cannot operate in total closed cycle mode. /lonticello Short canal Basin to towers and/or river Uses mechanical "helper" towers during warm parts of year. nner Mississinn Cannot operate in total closed cycle mode. Prairie Island Mississippi River 560 14,000-ft spray canal 784 Edge of river **Quad Cities** Upper Mississippi Mississippi River At shore t. Calhoun Missouri River 660 At shore Missouri 1359 At shoreline At shoreline <5% mean annual river flow ooper Missouri acreage includes fossil units Lower Mississippi Mississippi River 3561 At river bank At river bank NOTES: 6 sites in this situation.

1,750 ft from shore, 22 ft. At shoreline 908 deep reat Lake ake Michigan 2065 1,750 ft from shore Lake Michigan 2 Flumes 150 ft from shore Point Beach Great Lakes Lake Michigar 650 2,250 ft from shore 1,250 ft from shore DC Cook reat Lakes Lake bottom, 3100 ft. fron Open canal reat Lakes ake Ontario 488 Fitzpatrick Great Lakes Lake Ontario 702 ~850 ft. from shore To lake, ~1150 ft. from shore nit 1 uses once-through; unit 2 uses a natural draft tower ipelines 1,000 ft off sho 55 ft. long diffuser pipe Nine Mile Point Great Lakes Lake Ontario unit 3 will use a mechanical tower

Appendix C: Summary Tabulation of Number of NPPs in Each Situation (per App. B)

Summary of EPA 316(b) Pr	roposed Rule A	pplicability by	y Site and Unit	<u> </u>			
		COLINT DV CIT			COLL	NIT DV INIDIVIDI	LAL LINUT
		COUNT BY SIT	1	COUNT BY INDIVIDUAL U			1
			ALL SITES:			NEW PLANTS	ALL SITES:
CITIATION	OPERATING	NEW PLANT	OPERATING +		ERATING	(Greenfield +	OPERATING +
SITUATION	NPPs ONLY	SITES	NEW PLANT	NP	Ps ONLY	existing site)	NEW PLANT
All units on site (both existing and new) use closed cycle cooling towers (based		/*\ 2	25		/¢\ 2.	(0) 11	_
on cooling towers) 100% of the time 1B Once through cooling on a man-made cooling pond that is exempt from 316(b)	22	(*) 2	25		(\$) 34	(&) 11	4
(not "waters of the U.S."), making it effectively a CCC site ##		(**) 1	. 5		,		1
(not waters of the o.s.), making it effectively a ccc site ##	4	() 1	. 3			4	
Total CCC sites and reactors (Situations 1A + 1B)	26	3	29		(\$) 42	(&) 15	5
At least one unit on site uses once-through cooling 100% of the time.	39		39		62	2 (%) 7	6
TOTALS	65	3	68		* 104	1 (&) 22	12
	(*) 2 nov	greenfield si	tos (COLs)	(\$) i	ncludes	(&) includes	(%) these 7 new
		w greenfield		ANO-2	2 & NMP-2	Watts Bar-2 & Bellefonte-1	units will use CCC on existing OTC site
Breakdown of "Once Through sites" (Situations 2-7))							
Once-through on cooling pond with makeup from a small river with low flow ##							
(includes two cat 3 units at one site, and 3 cat 2 site, each with new units)	7	0	7		10	5	1
Once-through on a multi-purpose reservoir (includes 6 cat 3 units on 3 sites, and							
one Cat 2 site with one O-T unit and one CCC unit)	7	0	7		14	1 0	1
4 Once-through on ocean site (all cat 4)	7	0	7		1:	1 0	1
Once-through on estuary or tidal river (includes one cat 2 site [new unit])	6	0	6		1:	1 1	1
Once through on a large freshwater river (all Cat 4)	6	0	6			3 0	
Once through on Great Lake (includes one cat 2 site with an O-T unit, an							
operating CCC unit and a new CCC unit)	6	0	6			3 1	
TOTALS	39	0	39		62	2 (%) 7	6
NOTES:							
OPERATING PLANTS:							
Only currently operating plants with a full power operating license are listed (no	shutdown pla	nts)					
Adjacent plants NMP and Fitzpatrick considered separate sites because of differe							
Adjacent Salem and Hope Creek units operated by PSEG considered separate site							
Once-through site & unit listings include 12 reactors on 6 sites with helper tower							
NEW PLANTS							
Only new plants with a COL or ESP application currently on file with NRC are inclu	ided in this da	ta (i.e., Clintor	n-2. Piketon Ama	arillo G	reen River	etc. are not in	cluded)
New units with their COLA reviews suspended at NRC are not included (e.g., Call					CCII III VCI	, 210. 0.2 1101 111	
This listing considers the following new sites to be "greenfield" based on COLAs:	-			FSP apr	lication		
This listing considers adjacent Susquehanna (operating) and Bell Bend (planned)						re obvious	
Completion of Watts Bar-2 is included with new plants. Planned future completi				call			
25	2.7 G. Belleroll						
What these units on a man-made cooling pond are effectively closed cycle sy	ı Vstems equival	ent to cooling	tower technolog	v for n	irposes of	316(b).	

Appendix D: International Application of Once-Through Cooling vs. Closed-Cycle Cooling

Country	Fresh Water Closed cycle cooling	Saline Water (O/E/TR) Closed cycle cooling	Fresh Water Once-through cooling	Saline Water (O/E/TR) Once-through cooling	Total reactor units
Argentina	0	0		0	2
Armenia	1	0		0	1
Belgium	5	0		0	7
Brazil	0	0		2	2
Bulgaria	0	0		0	2
Canada	0	0		1	18
China, mainland	1	0		13	14
Czech Republic	6	0		0	6
Finland	0	0		4	4
France	32	0		18	58
Germany	10	0		3	17
Hungary	0	0		0	4
India	8	0		6	18
Japan	0	0		55	55
Korea RO (South)	0	0		20	20
Mexico	0	0		2	2
Netherlands	0	0		1	1
Pakistan	0	0		1	2
Romania	0	0		0	2
Russian Federation	3	0		4	32
Slovak Republic	4	0		0	4
Slovenia	0	0		0	1
South Africa	0	0		2	2
Spain	4	0		1	8
Sweden	0			10	10
Switzerland	2	0		0	5
Taiwan	0	0		6	6
Ukraine	4	0		0	15
United Kingdom	0	0		19	19
Non-US Subtotal	80	0	89	168	337
USA-East Coast (1)	16	1	12	18	47
USA-Great Lakes (2)	5	0		0	13
USA-Central (3)	16			0	36
USA-Western (4)	4	0		4	8
USA-TOTALS	41	1	40	22	104
GLOBAL TOTALS	121	1	129	190	441
				190	-4-1
USA DATA BY USGS (1) New England, Mid-A (2) Great Lakes region (3) Ohio, Tennessee, Up (4) Lower Colorado, Pac	Atlantic, South pper Mississipp	Atlantic-Gulf Di, Lower Missis		Arkansas-White	-Red, Texas Gulf
	Fresh Water Closed cycle	Saline Water (O/E/TR) Closed cycle	Fresh Water Once-through	Saline Water (O/E/TR) Once-through	
non-US totals, by %	cooling 24%			cooling 50%	
US totals, by %	39%	1%	39%	21%	

21%

39%

US totals, by %

39%

1%

Appendix E: EPRI National Cost Estimate for Retrofit of U.S. Power Plants with Closed-Cycle Cooling: Technical Brief — Clean Water Act Fish Protection Issues



EPRI National Cost Estimate for Retrofit of U.S. Power Plants with Closed-Cycle Cooling

Technical Brief - Clean Water Act Fish Protection Issues

Summary

EPRI's retrofit cost study indicates that the potential cost of closed-cycle cooling retrofits, based on capital costs and costs associated with lost revenue from outage time to install the towers and associated structures, plant inefficiencies and energy penalties, exceeds \$95 billion.

Background

The U.S. Environmental Protection Agency (EPA) is currently developing revised regulations for power plant cooling water intake structures under §316(b) of the Clean Water Act, which requires that "the location, design, construction and capacity of cooling water intake structures shall reflect the best technology available (BTA) for minimizing adverse environmental impact." EPA is considering technology-based aquatic life protection performance standards that may require closed-cycle cooling as BTA for existing thermoelectric facilities.

In once-through systems, cooling water is withdrawn from waters of the U.S., passed once through the power plant condenser cooling system and then returned to the source waterbody. Wet closed-cycle cooling systems differ in that the heated cooling water is not returned to the waterbody but is conveyed to a tower that utilizes evaporative cooling. Mechanical towers are the most common form of closed-cycle cooling. Other less commonly used closed-cycle cooling systems include natural draft, dry, and hybrid towers; and cooling ponds, enhanced ponds, and spray canals. Closed-cycle

cooling withdraws significantly less water than the once-through approach and, therefore, impinges and entrains fewer aquatic organisms. However, closed-cycle cooling consumes more water than once-through cooling and introduces other environmental and social impacts (e.g., noise, salt drift, icing, fogging, and visible vapor plumes).

EPRI has carried out a study to estimate the national cost of retrofitting existing once-through cooled facilities with closed-cycle cooling systems at 428 power facilities potentially subject to a retrofit requirement (based on their use of greater than 50 million gallons per day of oncethrough cooling water). These facilities generate approximately 312,000 MW of electricity, including 60,000 MW from 39 nuclear facilities and 252,000 MW from 389 fossil facilities. Detailed information on EPRI's approach and cost estimate results is contained in Closed-Cycle Retrofit Study: Capital and Performance Cost Estimates (EPRI Technical Report 1022491).

Approach

While closed-cycle cooling is commonly used at new facilities, the retrofit of existing facilities that use once-through cooling to closed-cycle cooling can be challenging or impractical for a variety of site-specific reasons, such as space constraints, layout of existing site infrastructure, economic factors and environmental issues. Thus, the initial step in this EPRI project was to assemble all available independent retrofit cost information to establish a probable range of costs. Inde-



pendent retrofit cost estimates for 82 facilities were obtained from individual utilities, and, as expected, showed a general trend of increasing costs with increasing plant once-through cooling water flow, but very large cost differences exist for any given flow.

Based on discussions with plant personnel and architect-engineering firms and the application of professional judgment, EPRI then developed a list of eleven factors which were believed to be the important influences that determine the sitespecific degree of retrofit difficulty. A model was developed using the 82 sitespecific retrofit cost estimates and facility flow to establish cost estimates for the various degrees of retrofit difficulty (easy, average, difficult and more difficult for fossil facilities and difficult and more difficult for nuclear facilities). Additional information to evaluate these eleven factors for individual facilities was solicited from the entire population of potentially affected facilities. Adequate information was obtained from 125 facilities to con-

duct a site-specific degree of difficulty analysis to estimate the capital cost (cost of equipment, materials and construction to build cooling towers and connecting pipes). The proportional allocations of the degree of difficulty for the 125 facilities were then used to estimate the national capital cost of retrofits. In this analysis, EPRI assumes the use of wet mechanical draft cooling towers since they are most commonly used. Only one natural draft tower has been constructed in the last two decades. If natural draft towers are constructed, capital cost would increase while lost revenue for operating power would be reduced. EPRI also estimated three additional retrofit costs as a result of lost revenue due to the:

- 1. Extended outage necessary for tower installation at some facilities
- 2. Heat rate penalty for most facilities resulting from reduced cooling efficiency
- 3. Increased operating power requirements for mechanical cooling towers (fans and pumps)

Closed-cycle cooling costs <u>not</u> estimated in this study include costs of permitting, financing, labor and chemical O&M, replacement power for facilities prematurely retired for economic or other reasons, electric system upgrades due to premature retirements and lost generation due to the use of power for the cooling tower and heat rate penalty, and the social and environmental costs of cooling tower operation.

The capital costs were aggregated and extrapolated along with estimates of lost revenue due to extended outage time, operating energy requirements for the cooling tower and the heat rate penalty to provide an estimated national total net present value and annualized costs assuming retrofit of all 428 facilities.

Results

Retrofit Capital Costs: EPRI estimates a net present value of \$62 billion (\$19.6 and \$42.4 billion for nuclear and fossil facilities, respectively) in capital costs to retrofit the 428 once-through cooled facilities. While uncertainties in the estimated capital cost exist, analyses that compared the EPRI correlation-based estimates to facility-specific independent cost estimates found them to be within ±10%, indicating the methodology is reasonably robust for the purpose of estimating the national capital cost.

Extended Outage Revenue Loss: In most cases, cooling tower construction can be completed while the facility continues to operate and generate electric power and the final tie-in of the closed-cycle cooling system can take place during a normal scheduled maintenance outage. For other facilities an extended outage may be required. Some reasons for an extended outage include: 1) re-location of existing infrastructure necessary for electric power generation, 2) water pressure concerns due to site elevations may require replacing or re-enforcing water tunnels and 3) baseloaded facilities with a relatively long remaining life (e.g., nuclear plants) may re-optimize the cooling system to improve energy efficiency. Based on predicted outage times for nuclear and fossil facilities, the estimated national cost of extended outages is a net present value of \$17.3 billion (\$8.3 billion for nuclear facilities and \$9.0 billion for fossil facilities).

Cost (Billions)	Nuclear	Fossil	Total
Net Present Value*	\$31.9	\$63.3	\$95.2
Annualized Cost	\$2.3	\$4.7	\$ <i>7</i> .0

^{*} Assumes a 30 year system life

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Heat Rate Penalty: Reduced condenser cooling efficiency from a closed-cycle system compared to once-through cooling will result in an overall net reduction in electricity production output for most facilities. Conversion of a once-through cooling system to a closed-cycle cooling system using a wet cooling tower frequently results in an increase in the achievable turbine backpressure for most of the year and a corresponding loss of plant efficiency and output for most facilities. In most circumstances, EPRI estimates an output penalty of about 1.2% for the hottest 10% of the year and 0.9% for the remainder of the year. Assuming a generation cost of \$35/MWh, lost revenues from this heat rate penalty are estimated at \$527 million/yr for fossil facilities and \$182 million for nuclear facilities, for a combined total of \$709 million/yr. This equates to a net present value of \$8.8

Energy Penalty: Closed-cycle cooling retrofits will cause a net generation decrease since some of the facility generation output must be used to operate fans and additional water pumps for the closedcycle cooling system. EPRI estimates that the sum of the additional pumping and fan power results in an energy penalty that ranges from 0.9 to 1.7% of plant output; with a mid-range value of 1.3% (or 13 kW for a 1,000 MW plant). Assuming a generation cost of \$35/MWh, the estimated cost of the combined energy requirements is \$568 million (\$427 million for fossil and \$141 million for nuclear) which equates to a net present value of \$7.1 billion.

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